US011354223B2

(12) United States Patent
Peng et al.

(10) Patent No.: US 11,354,223 B2
(45) Date of Patent: Jun. 7, 2022

(54) MAXIMALLY PARALLEL TEST SCRIPT EXECUTION

(71) Applicant: **MICRO FOCUS LLC**, Santa Clara, CA (US)

(72) Inventors: **Jun-Chen Peng**, Shanghai (CN); **Xiang Gao**, Shanghai (CN); **Kai Long**, Shanghai (CN); **Ruixiang Chen**, Shanghai (CN); **Lingli Wu**, Shanghai (CN)

(73) Assignee: **MICRO FOCUS LLC**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 108 days.

(21) Appl. No.: **16/808,882**

(22) Filed: **Mar. 4, 2020**

(65) **Prior Publication Data**

US 2021/0279166 A1 Sep. 9, 2021

(51) **Int. Cl.**

G06F 11/36	(2006.01)
G06F 9/30	(2018.01)
G06F 9/38	(2018.01)

(52) **U.S. Cl.**

CPC ***G06F 11/3676*** (2013.01); ***G06F 9/3005*** (2013.01); ***G06F 9/3842*** (2013.01); ***G06F 11/3684*** (2013.01); ***G06F 11/3692*** (2013.01)

(58) **Field of Classification Search**

CPC G06F 11/3664; G06F 11/3684; G06F 11/3688; G06F 11/3692; G06F 11/3672; G06F 11/3676; G06F 8/314; G06F 8/445; G06F 8/45

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,477,583	B2	10/2016	Maddela	
2011/0145643	A1*	6/2011	Kumar	G06F 11/263 714/33
2012/0297389	A1*	11/2012	Haham	G06F 8/451 718/102
2015/0100829	A1	4/2015	Nanjundappa et al.	
2018/0137035	A1*	5/2018	Magre	G06F 11/3692
2018/0173606	A1	6/2018	Malla et al.	
2019/0196950	A1	6/2019	Ranganathan et al.	

OTHER PUBLICATIONS

Kinsbruner, "How to Scale (Up) your Test Automation Practices and Achieve Better APP Quality", Mobile Technical Evangelist at Perfecto, Jan. 18, 2018.

"Accelerated Test Automation for Web and Mobile, Smarter Test Execution Awaits", 2019, https://www.perfecto.io/products/platform/smart-test-execution, 7 pp.

"UFT Mobile—Appium (Open Source) Extension", Microfocus Inc., 2019 https://www.microfocus.com/media/flyer/uft-mobile-appium-open-source-extension-flyer.pdf.

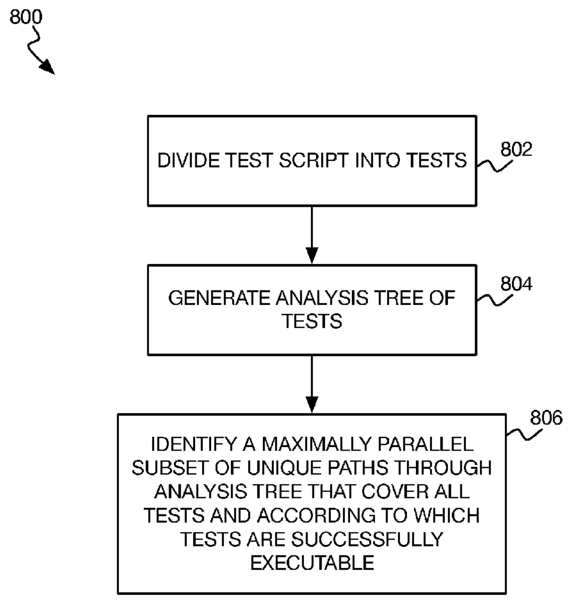
* cited by examiner

Primary Examiner — Duy Khuong T Nguyen

(57) **ABSTRACT**

A test script is divided into tests having a sequential order within the test script. An analysis tree of the tests can be generated. Each unique path through the analysis tree includes a subset of the tests as sequentially ordered within the test script. A maximally parallel subset of the unique paths that covers all the tests and according to which the tests are successfully executable is identified. Each test appears in only one unique path of the maximally parallel subset.

20 Claims, 16 Drawing Sheets



800
DIVIDE TEST SCRIPT INTO TESTS
802
GENERATE ANALYSIS TREE OF TESTS
804
IDENTIFY A MAXIMALLY PARALLEL SUBSET OF UNIQUE PATHS THROUGH ANALYSIS TREE THAT COVER ALL TESTS AND ACCORDING TO WHICH TESTS ARE SUCCESSFULLY EXECUTABLE
806

FIG 1

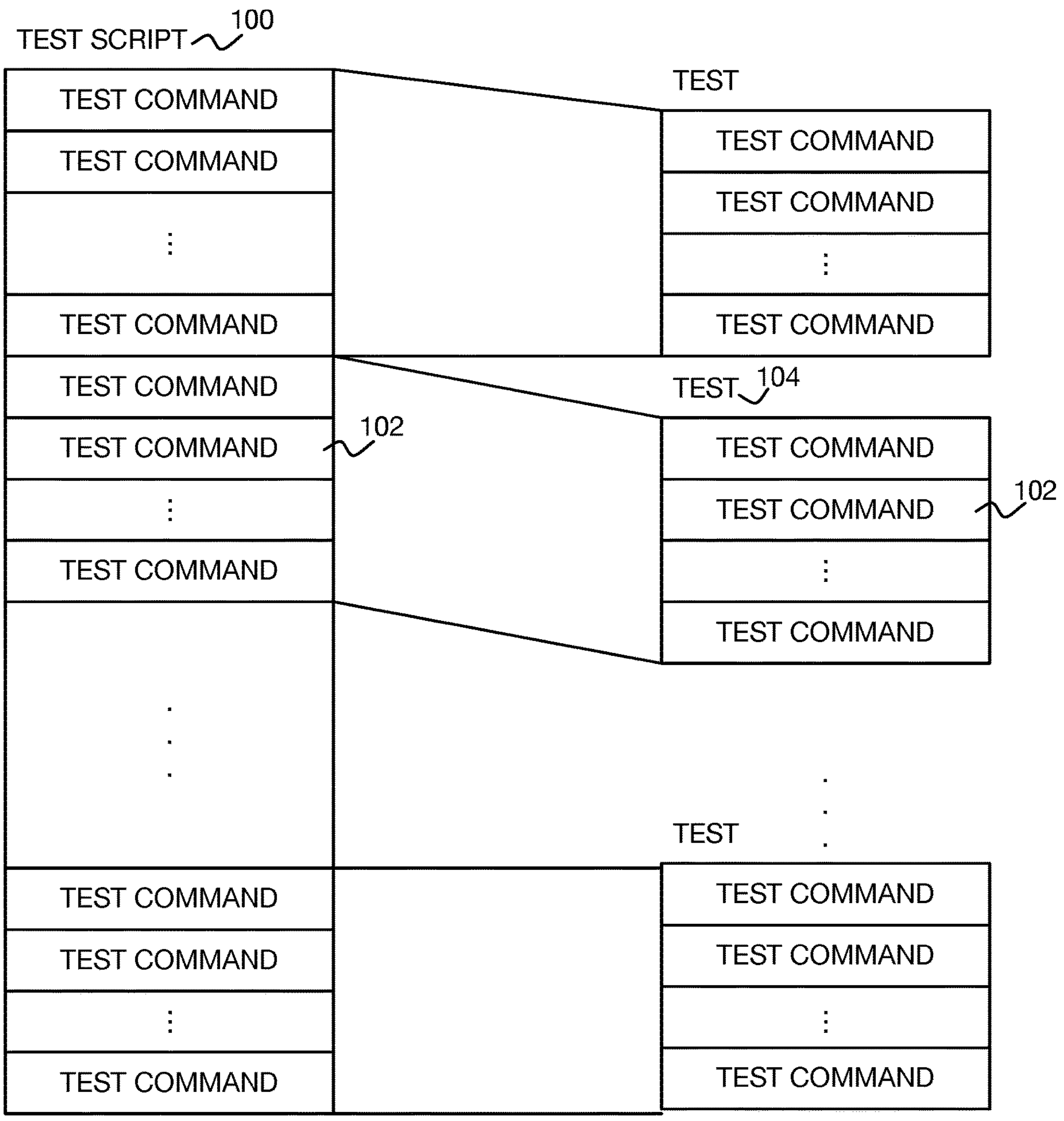
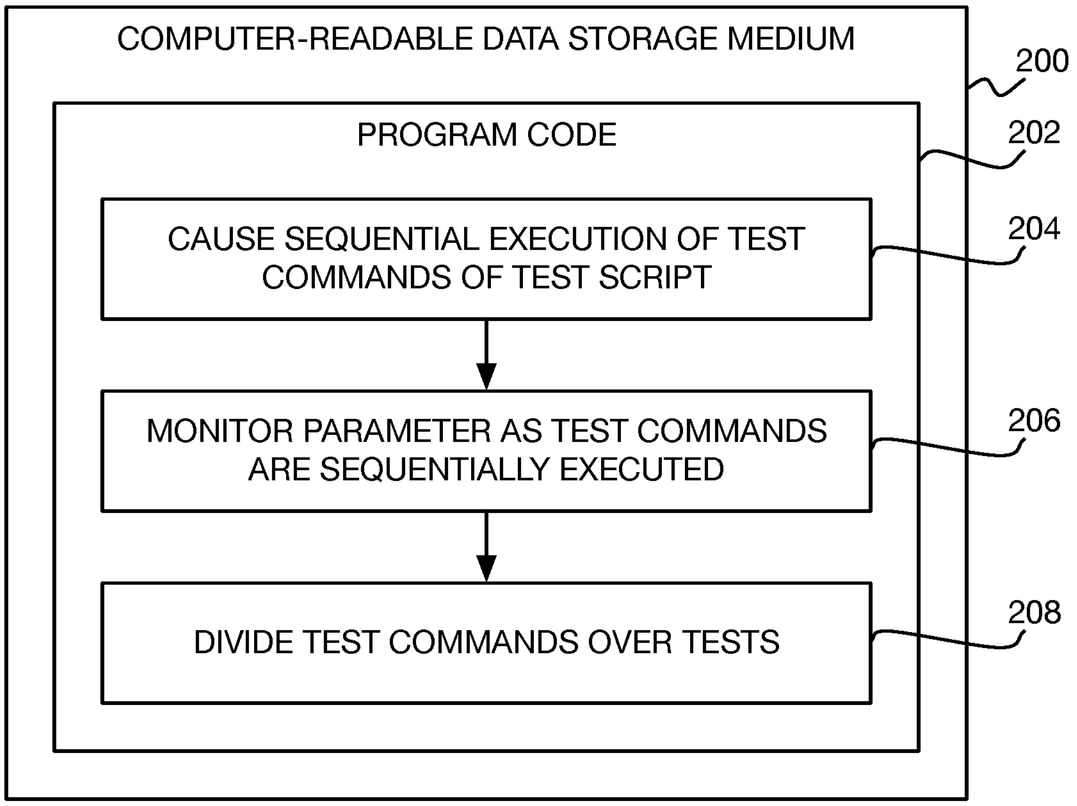

TEST SCRIPT
100
TEST COMMAND
TEST COMMAND
TEST COMMAND
TEST COMMAND
TEST COMMAND
102
TEST COMMAND
TEST COMMAND
TEST COMMAND
TEST COMMAND
TEST COMMAND
TEST
TEST COMMAND
TEST COMMAND
TEST COMMAND
TEST
104
TEST COMMAND
TEST COMMAND
102
TEST COMMAND
TEST
TEST COMMAND
TEST COMMAND
TEST COMMAND

FIG 2


COMPUTER-READABLE DATA STORAGE MEDIUM
200
PROGRAM CODE
202
CAUSE SEQUENTIAL EXECUTION OF TEST COMMANDS OF TEST SCRIPT
204
MONITOR PARAMETER AS TEST COMMANDS ARE SEQUENTIALLY EXECUTED
206
DIVIDE TEST COMMANDS OVER TESTS
208

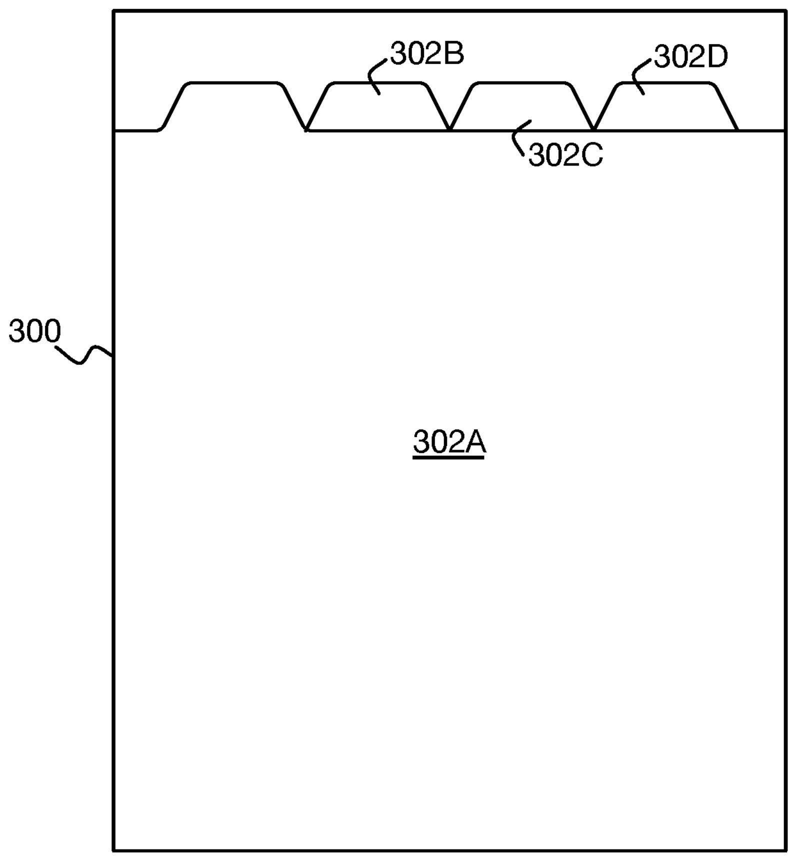


FIG 3A

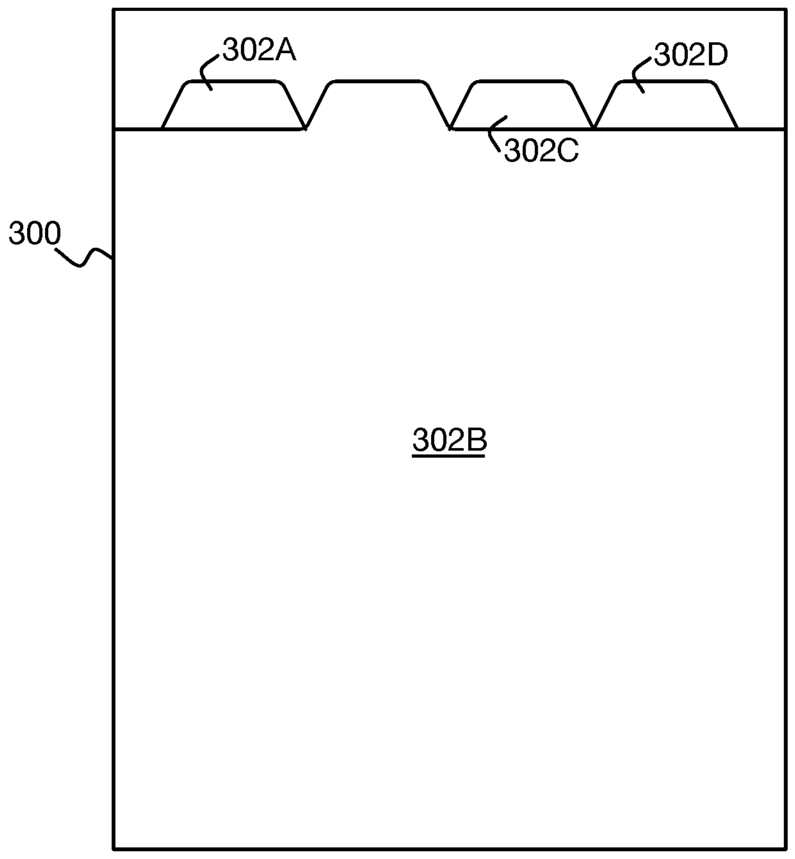
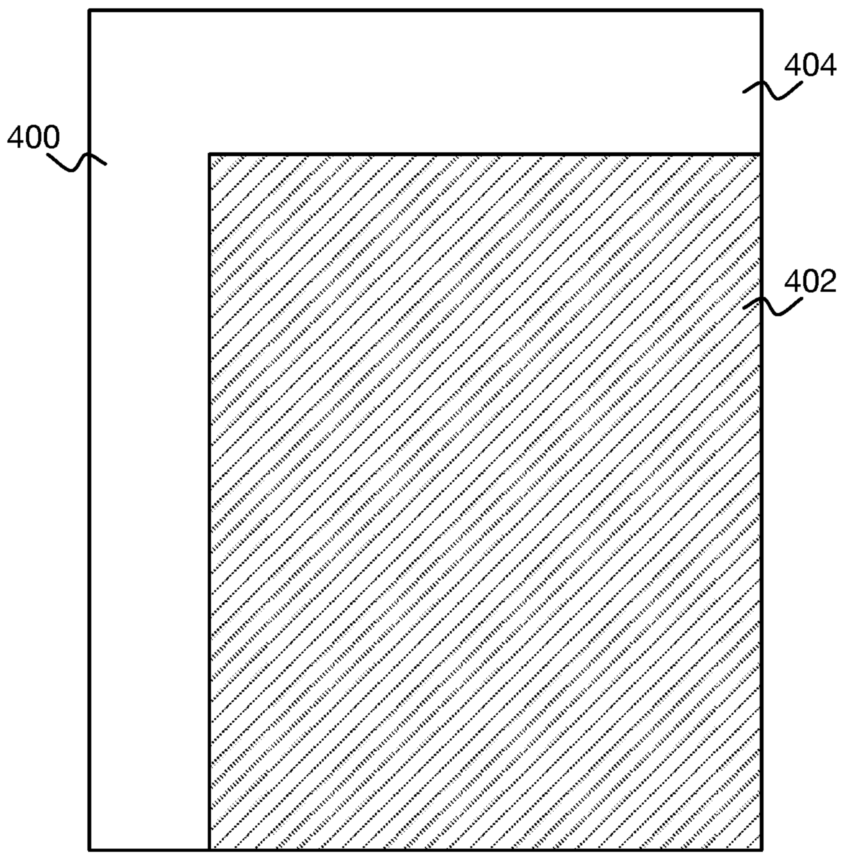


FIG 3B

FIG 4



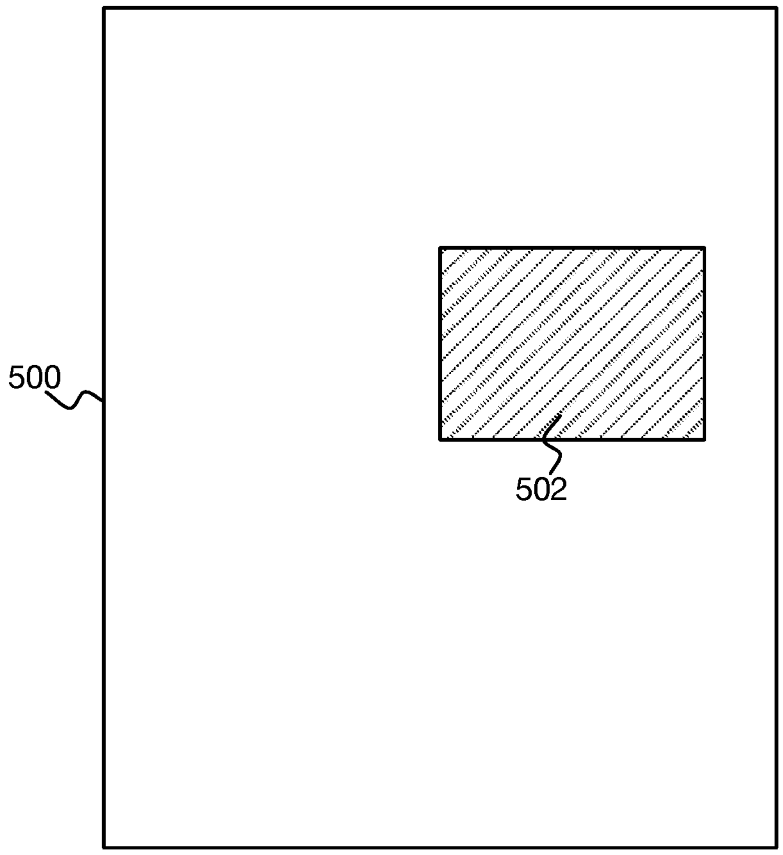


FIG 5A

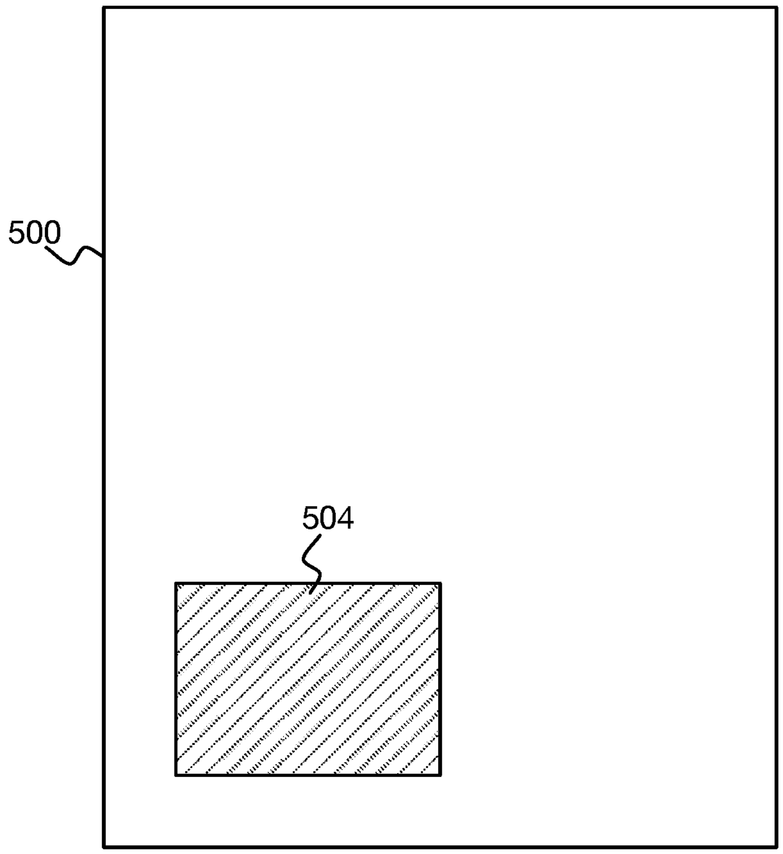


FIG 5B

FIG 6

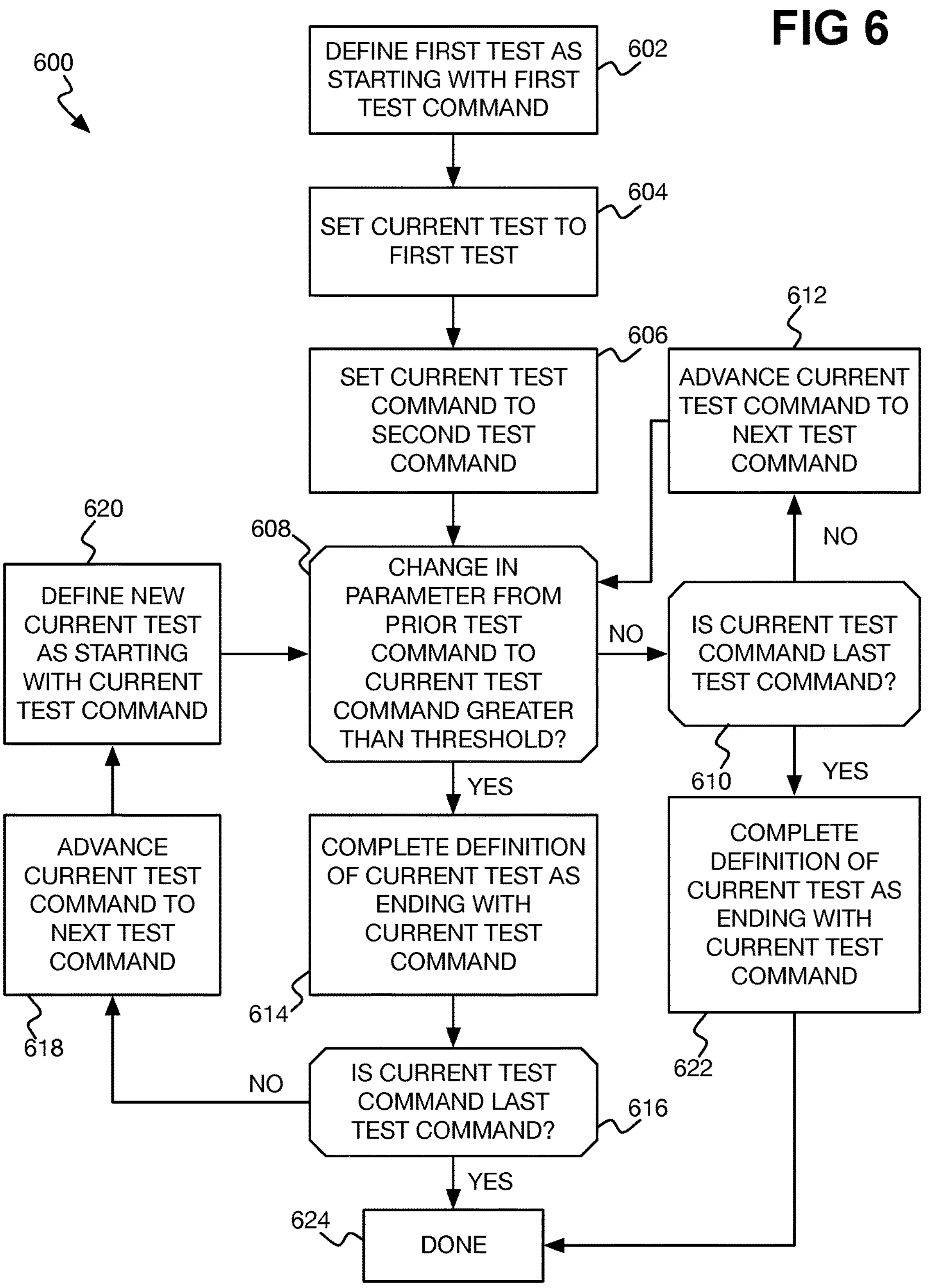

600
DEFINE FIRST TEST AS STARTING WITH FIRST TEST COMMAND
602
SET CURRENT TEST TO FIRST TEST
604
SET CURRENT TEST COMMAND TO SECOND TEST COMMAND
606
ADVANCE CURRENT TEST COMMAND TO NEXT TEST COMMAND
612
NO
CHANGE IN PARAMETER FROM PRIOR TEST COMMAND TO CURRENT TEST COMMAND GREATER THAN THRESHOLD?
608
NO
IS CURRENT TEST COMMAND LAST TEST COMMAND?
610
YES
DEFINE NEW CURRENT TEST AS STARTING WITH CURRENT TEST COMMAND
620
YES
ADVANCE CURRENT TEST COMMAND TO NEXT TEST COMMAND
618
COMPLETE DEFINITION OF CURRENT TEST AS ENDING WITH CURRENT TEST COMMAND
614
COMPLETE DEFINITION OF CURRENT TEST AS ENDING WITH CURRENT TEST COMMAND
622
NO
IS CURRENT TEST COMMAND LAST TEST COMMAND?
616
YES
DONE
624

FIG 7A

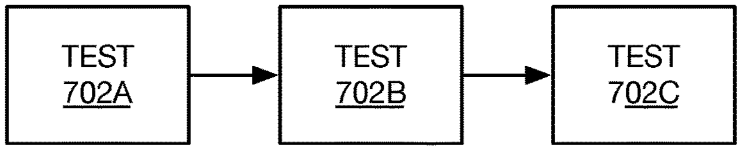


FIG 7B

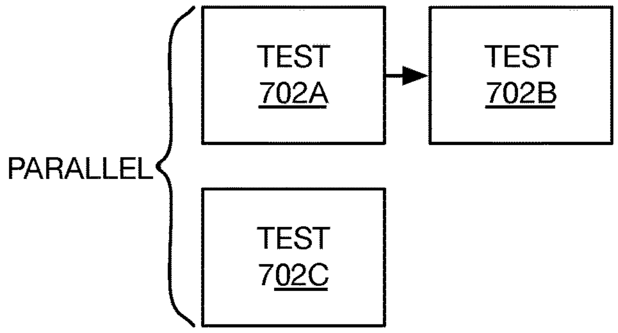


FIG 7C

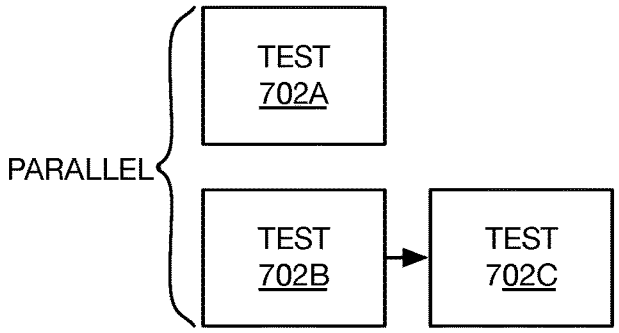


FIG 7D

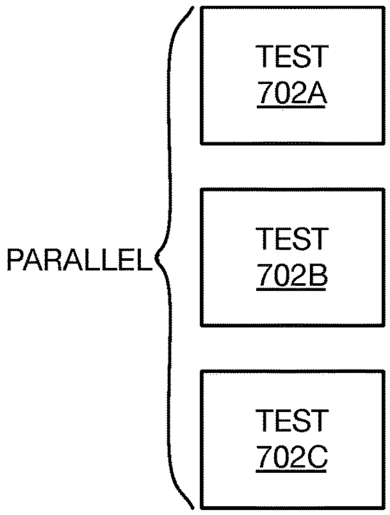


FIG 8

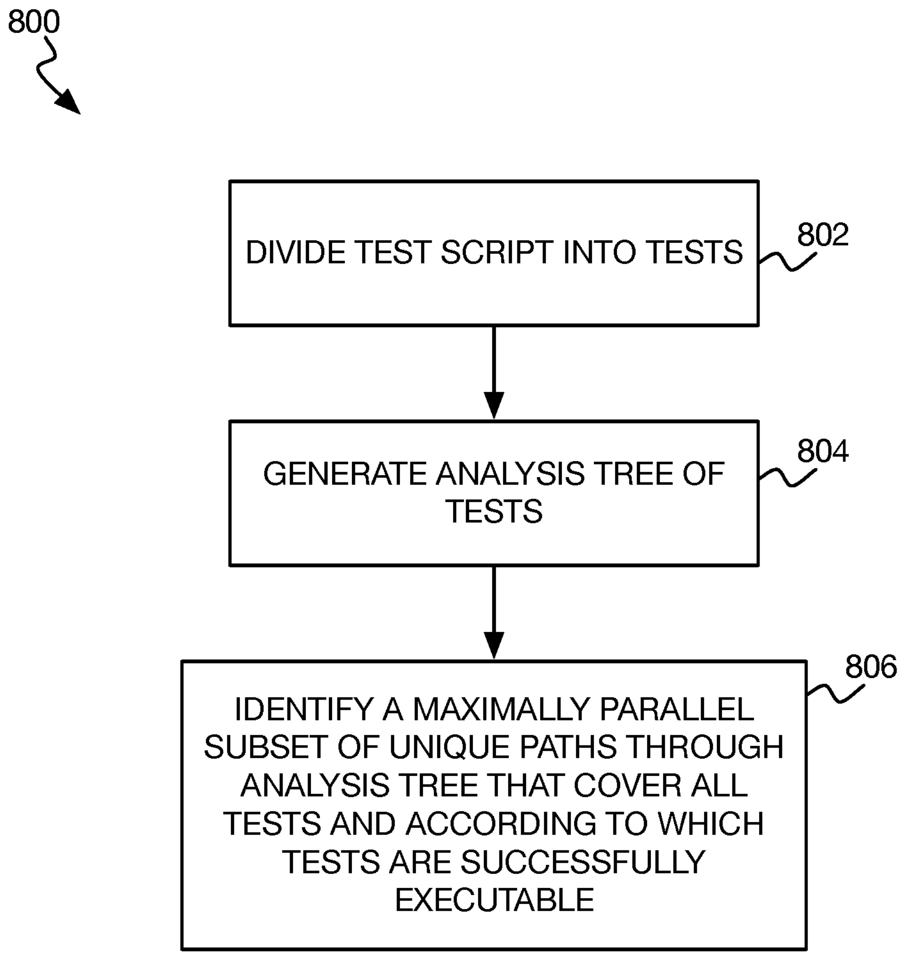

800
DIVIDE TEST SCRIPT INTO TESTS
802
GENERATE ANALYSIS TREE OF TESTS
804
IDENTIFY A MAXIMALLY PARALLEL SUBSET OF UNIQUE PATHS THROUGH ANALYSIS TREE THAT COVER ALL TESTS AND ACCORDING TO WHICH TESTS ARE SUCCESSFULLY EXECUTABLE
806

FIG 9

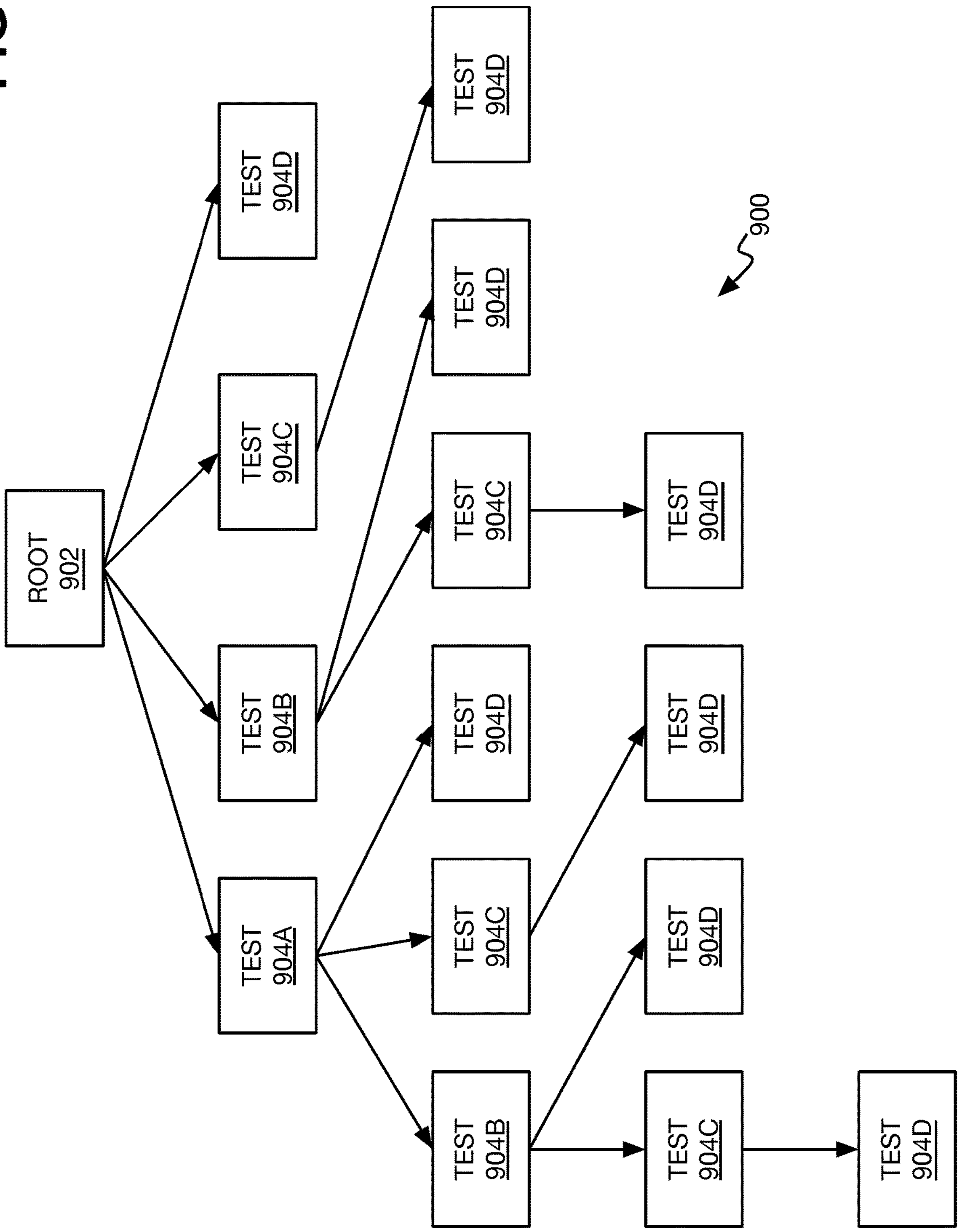


FIG 10

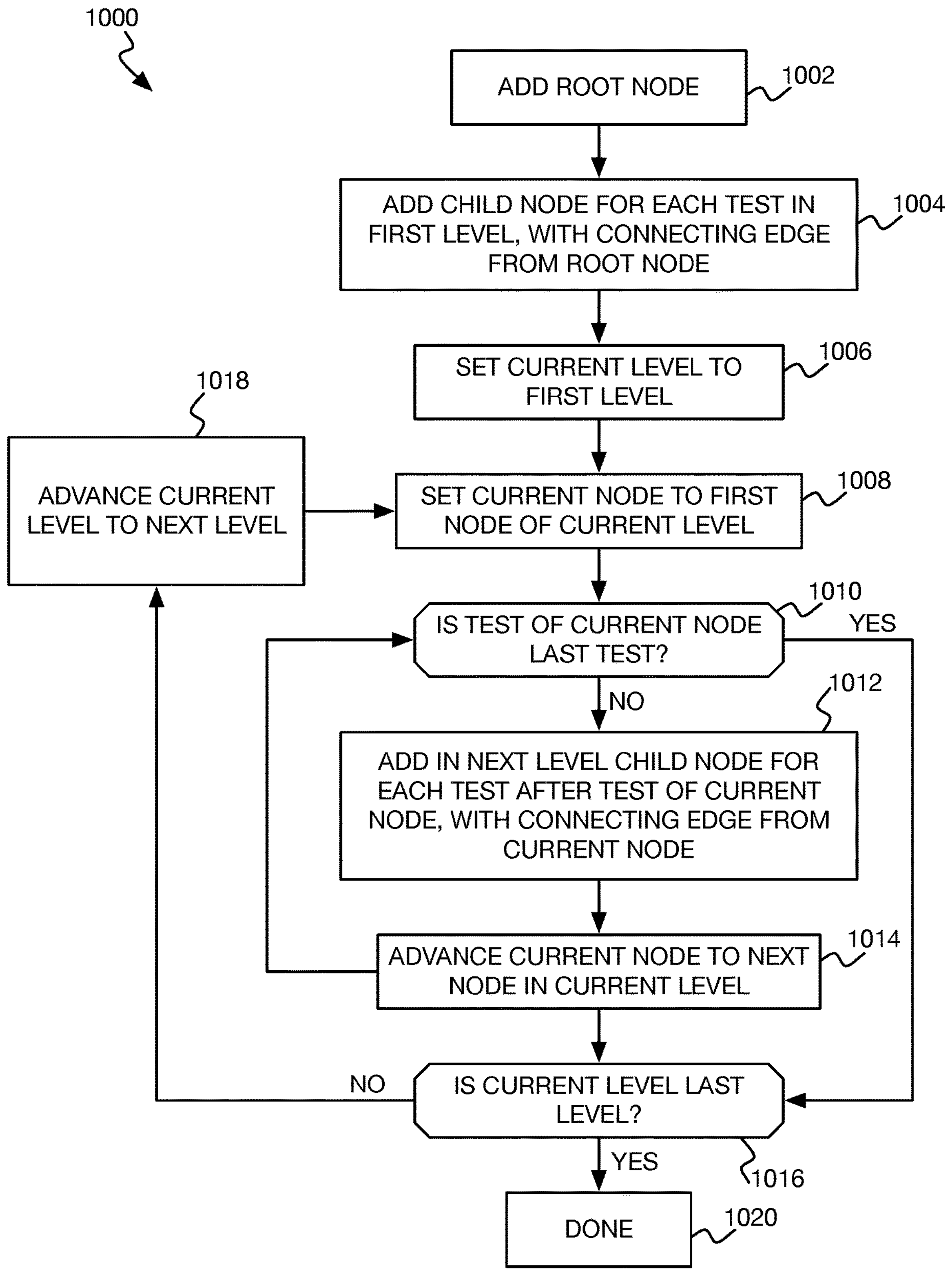

1000
ADD ROOT NODE
1002
ADD CHILD NODE FOR EACH TEST IN FIRST LEVEL, WITH CONNECTING EDGE FROM ROOT NODE
1004
SET CURRENT LEVEL TO FIRST LEVEL
1006
1018
ADVANCE CURRENT LEVEL TO NEXT LEVEL
SET CURRENT NODE TO FIRST NODE OF CURRENT LEVEL
1008
IS TEST OF CURRENT NODE LAST TEST?
1010
YES
NO
1012
ADD IN NEXT LEVEL CHILD NODE FOR EACH TEST AFTER TEST OF CURRENT NODE, WITH CONNECTING EDGE FROM CURRENT NODE
ADVANCE CURRENT NODE TO NEXT NODE IN CURRENT LEVEL
1014
NO
IS CURRENT LEVEL LAST LEVEL?
YES
1016
DONE
1020

FIG 11

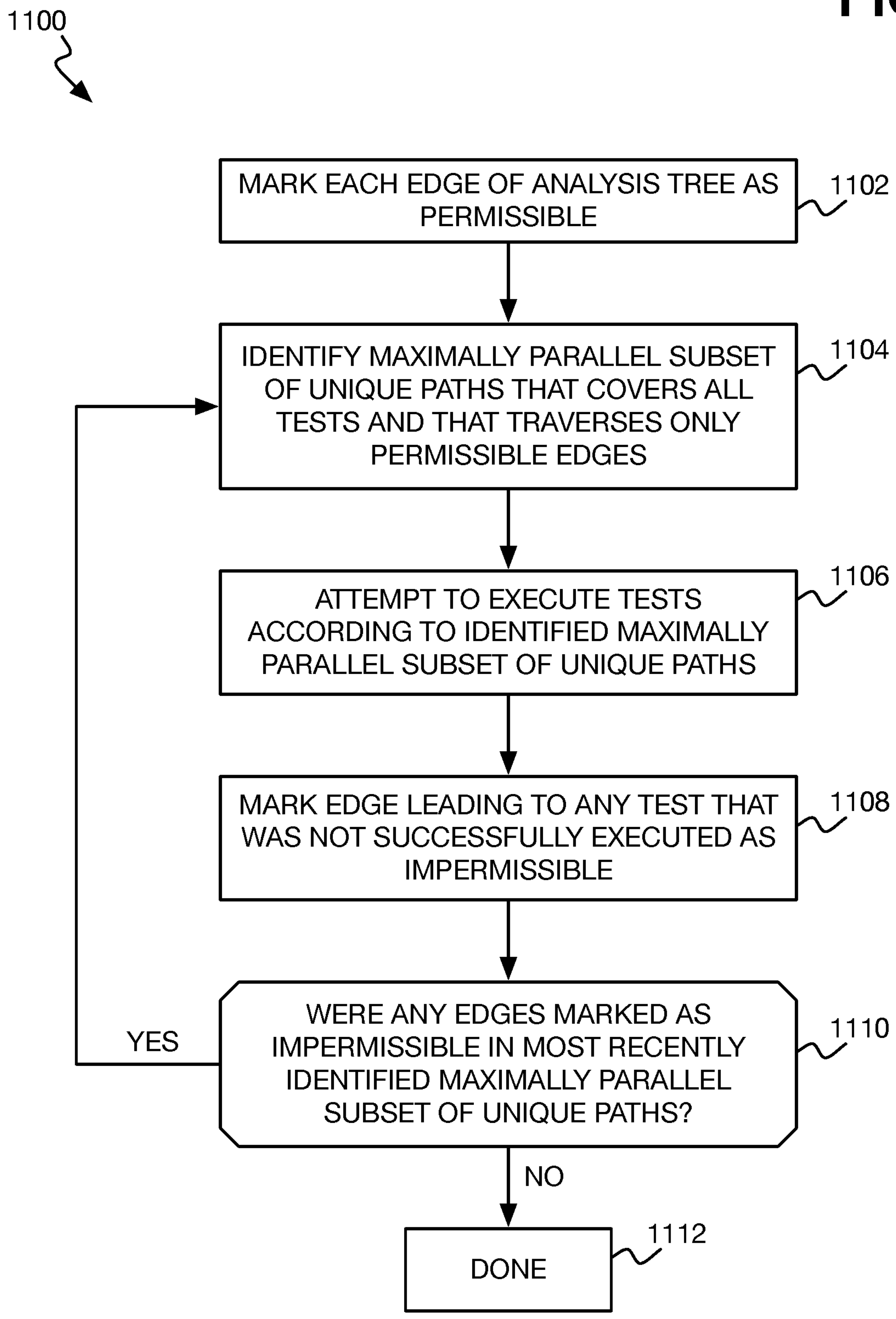

1100
MARK EACH EDGE OF ANALYSIS TREE AS PERMISSIBLE
1102
IDENTIFY MAXIMALLY PARALLEL SUBSET OF UNIQUE PATHS THAT COVERS ALL TESTS AND THAT TRAVERSES ONLY PERMISSIBLE EDGES
1104
ATTEMPT TO EXECUTE TESTS ACCORDING TO IDENTIFIED MAXIMALLY PARALLEL SUBSET OF UNIQUE PATHS
1106
MARK EDGE LEADING TO ANY TEST THAT WAS NOT SUCCESSFULLY EXECUTED AS IMPERMISSIBLE
1108
WERE ANY EDGES MARKED AS IMPERMISSIBLE IN MOST RECENTLY IDENTIFIED MAXIMALLY PARALLEL SUBSET OF UNIQUE PATHS?
1110
YES
NO
DONE
1112

FIG 12A

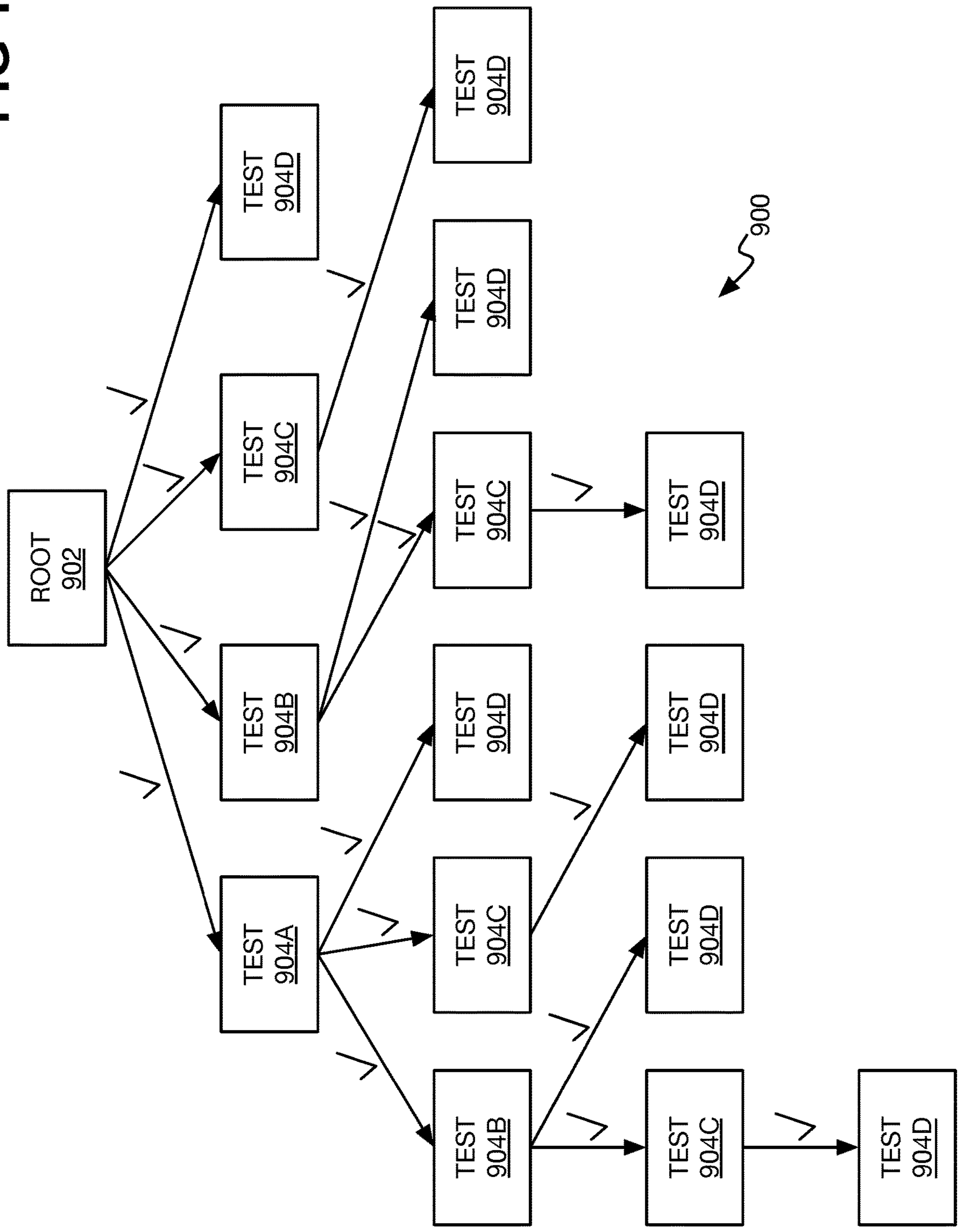

ROOT 902
TEST 904A
TEST 904B
TEST 904C
TEST 904D
TEST 904B
TEST 904C
TEST 904D
TEST 904C
TEST 904D
TEST 904D
TEST 904C
TEST 904D
TEST 904D
TEST 904D
TEST 904D
900

FIG 12B

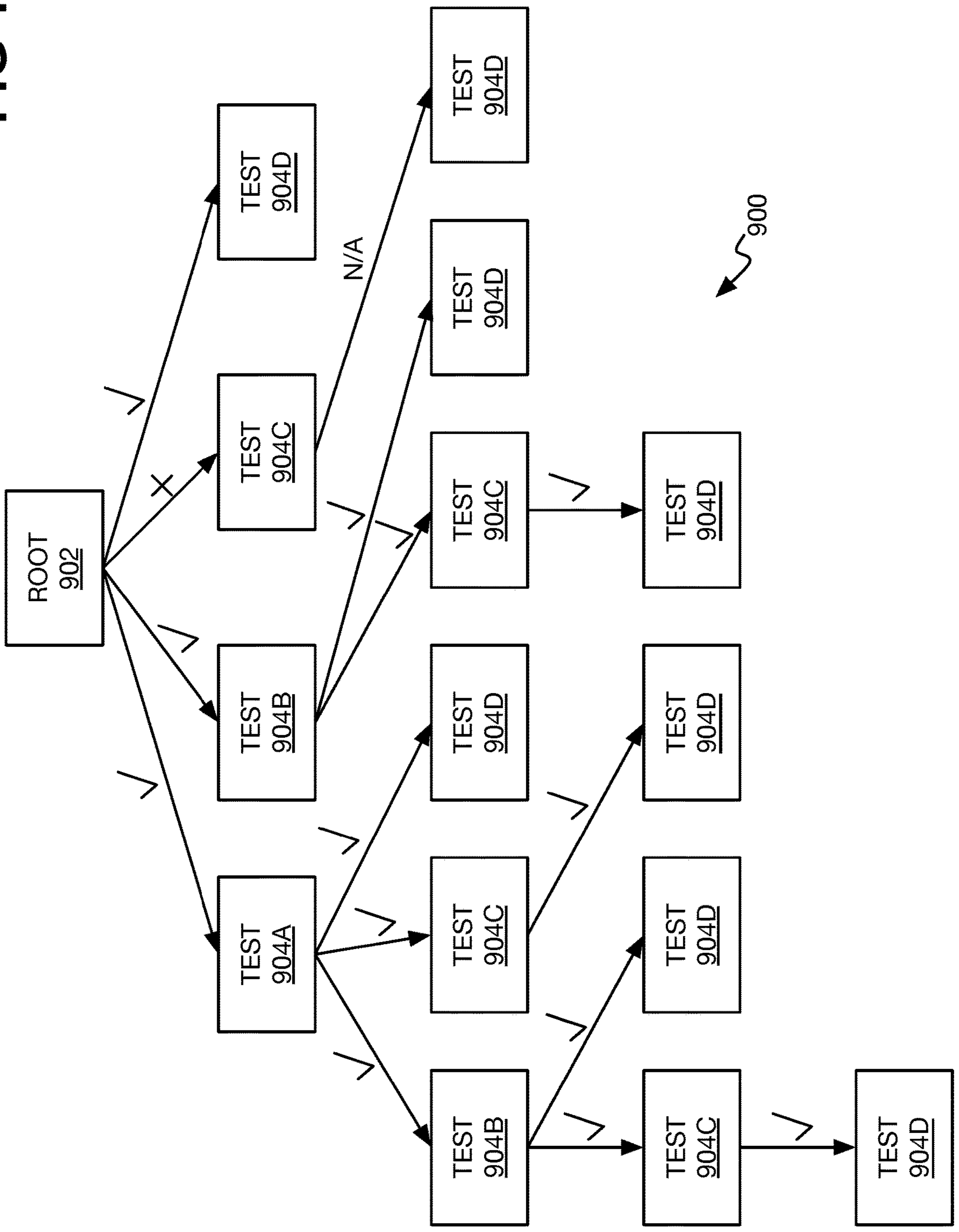

ROOT 902
TEST 904A
TEST 904B
TEST 904C
TEST 904D
TEST 904D
TEST 904C
TEST 904B
TEST 904D
TEST 904C
TEST 904D
TEST 904D
TEST 904D
TEST 904D
TEST 904C
TEST 904D
TEST 904D
N/A
900

FIG 12C

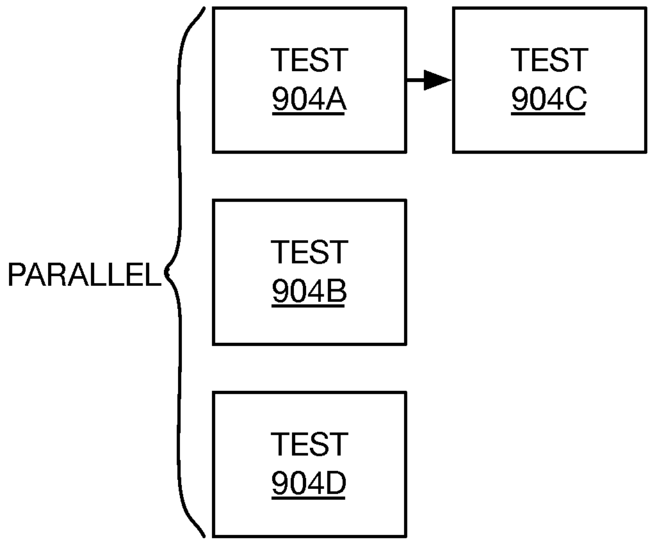


FIG 13

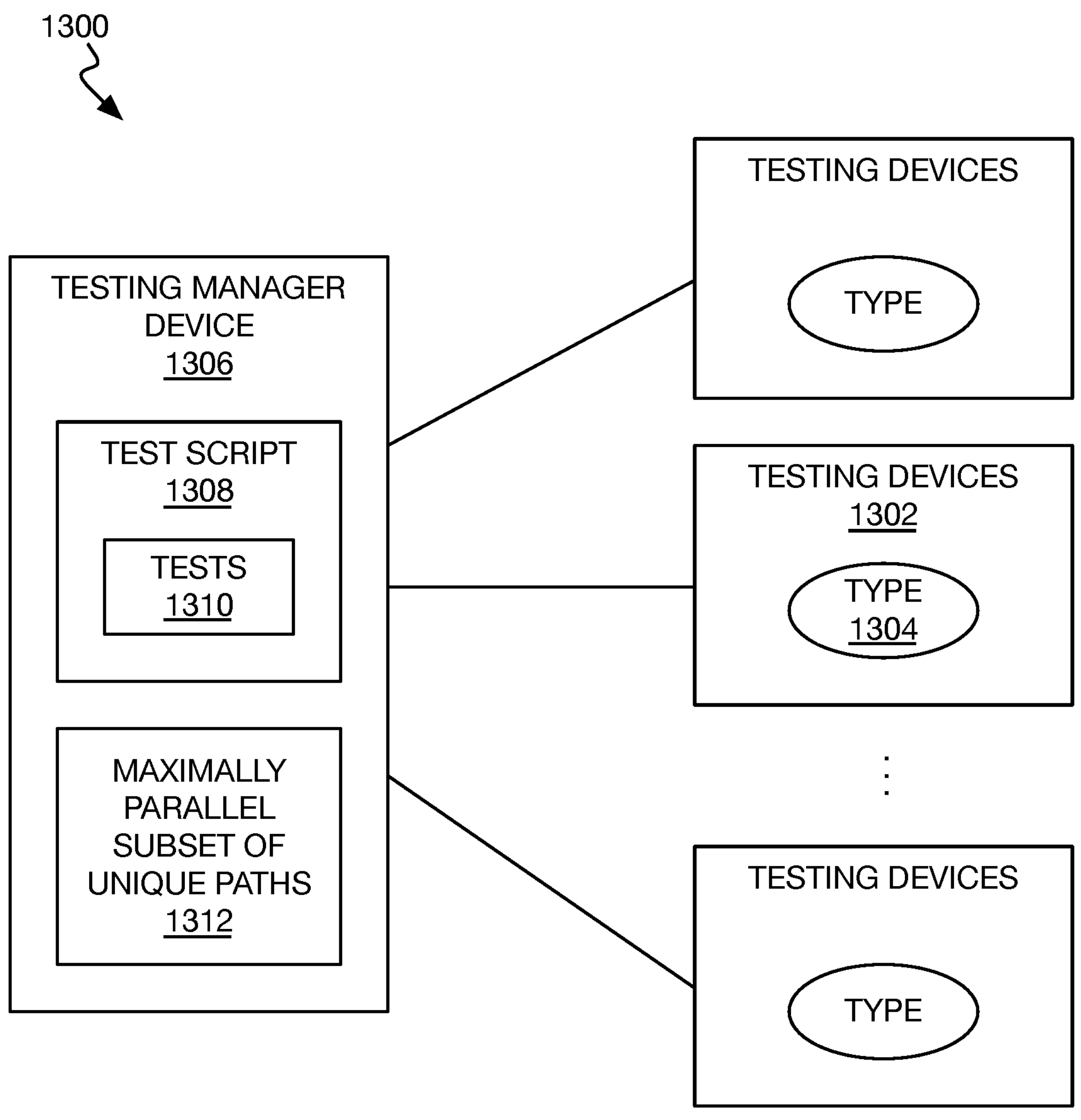
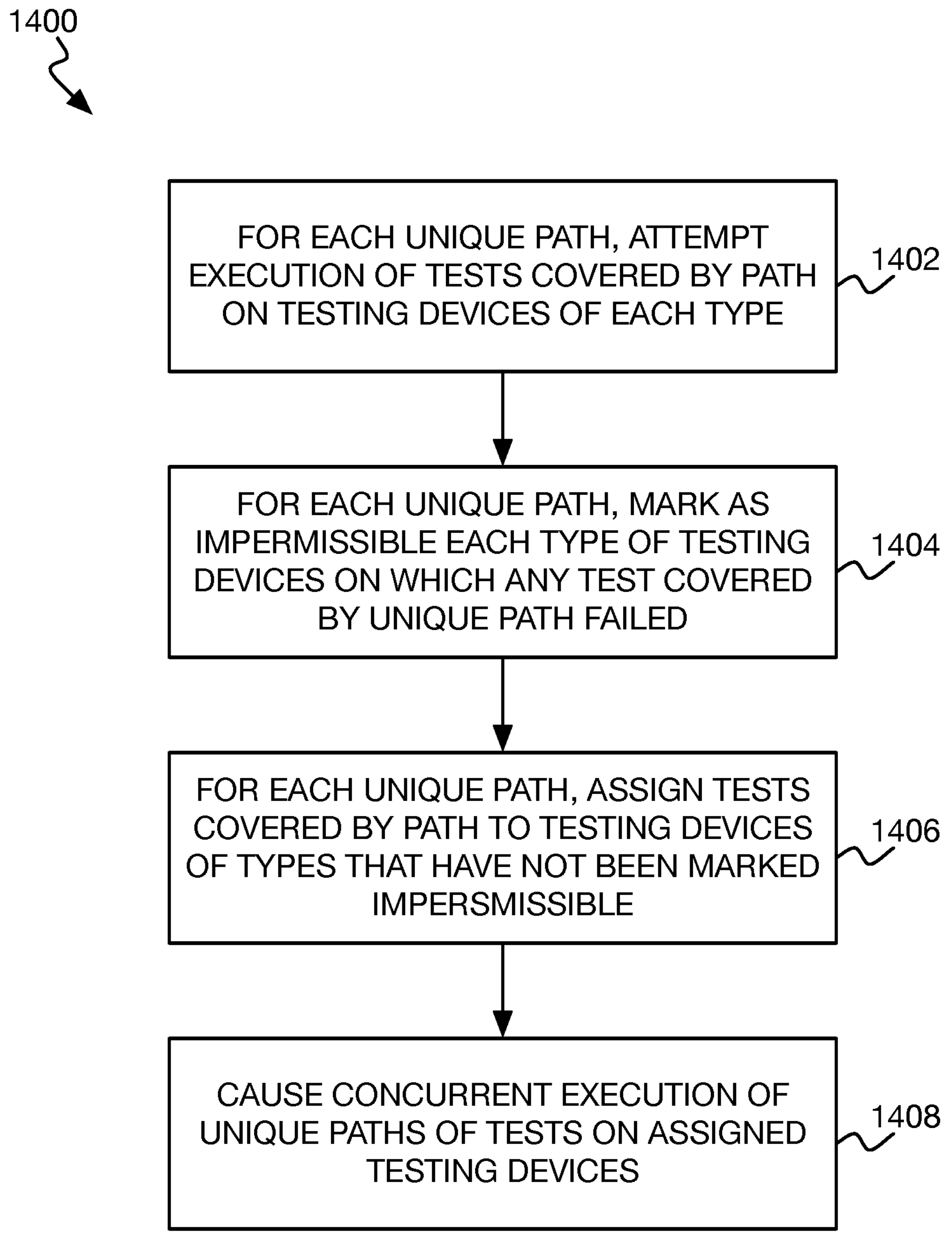

1300
TESTING MANAGER DEVICE 1306
TEST SCRIPT 1308
TESTS 1310
MAXIMALLY PARALLEL SUBSET OF UNIQUE PATHS 1312
TESTING DEVICES
TYPE
TESTING DEVICES 1302
TYPE 1304
TESTING DEVICES
TYPE

FIG 14


1400
FOR EACH UNIQUE PATH, ATTEMPT EXECUTION OF TESTS COVERED BY PATH ON TESTING DEVICES OF EACH TYPE
1402
FOR EACH UNIQUE PATH, MARK AS IMPERMISSIBLE EACH TYPE OF TESTING DEVICES ON WHICH ANY TEST COVERED BY UNIQUE PATH FAILED
1404
FOR EACH UNIQUE PATH, ASSIGN TESTS COVERED BY PATH TO TESTING DEVICES OF TYPES THAT HAVE NOT BEEN MARKED IMPERSMISSIBLE
1406
CAUSE CONCURRENT EXECUTION OF UNIQUE PATHS OF TESTS ON ASSIGNED TESTING DEVICES
1408

MAXIMALLY PARALLEL TEST SCRIPT EXECUTION

BACKGROUND

Computing devices like desktop, laptop, and other types of computers, as well as mobile computing devices like smartphones, among other types of computing devices, run software, which can be referred to as applications, to perform intended functionality. An application may be a so-called native application that runs on a computing device directly, or may be a web application or "app" at least partially run on remote a computing device accessible over a network, such as via a web browser running on a local computing device. To ensure that an application has been developed correctly to perform its intended functionality and that the application is operating correctly, the application may be tested.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram of an example test script having test commands divided into tests.

FIG. **2** is a diagram of an example computer-readable data storage medium storing program code for dividing test commands of a test script into tests.

FIGS. **3**A and **3**B are diagrams depicting an example of how execution of a test command of a test script can signify the start of a new test, with respect to a user interface of an application under test (AUT).

FIG. **4** is a diagram depicting another example of how execution of a test command of a test script can signify the start of a new test, with respect to a user interface of an AUT.

FIGS. **5**A and **5**B are diagrams depicting still another example of how execution of a test command of a test script can signify the start of a new test, with respect to a user interface of an AUT.

FIG. **6** is a flowchart of an example method for dividing test commands of a test script into tests, and which can be performed as a part of the processing of FIG. **2**.

FIGS. **7**A, **7**B, **7**C and **7**D are diagrams of examples as to how three tests into which a test script has been divided can be executed in different parallel and serial combinations.

FIG. **8** is a flowchart of an example method for identifying a maximally parallel subset of unique paths of tests into which a test script has been divided and that can be successfully executed in parallel.

FIG. **9** is a diagram of an example analysis tree of tests into which a test script has been divided and that has unique paths including subsets of the tests as sequentially ordered within the test script.

FIG. **10** is a flowchart of an example method for generating an analysis tree of tests into which a test script has been divided and that has unique paths including subsets of the tests as sequentially ordered within the test script.

FIG. **11** is a flowchart of an example method for identifying a maximally parallel subset of unique paths within an analysis tree of tests into which a test script has been divided and that can be successfully executed in parallel.

FIGS. **12**A, **12**B, and **12**C are diagrams depicting example performance of the method of FIG. **11** to identify a maximally parallel subset of unique paths within the analysis tree of FIG. **9**.

FIG. **13** is a diagram of an example system including testing devices of different types on which tests encompassed by a maximally parallel subset of unique paths can be assigned for concurrent execution of the unique paths.

FIG. **14** is a flowchart of an example method for assigning tests encompassed by a maximally parallel subset of unique paths to testing devices of different types for concurrent execution of the unique paths.

DETAILED DESCRIPTION

As noted in the background, an application is a computer program that is run, or executed, to perform intended functionality, and which may be tested to ensure that the application performs its intended functionality correctly. An application being tested may be referred to as an application under test (AUT). An AUT may expose a user interface that includes user interface objects, such as check boxes, buttons, text boxes, and other types of objects. During testing, the user interface objects may be selected in a defined sequence of test commands of a test script to verify that the application operates as expected.

While the test commands of a test script are sequentially ordered within the test script, groups of test commands, referred to herein as tests of the test script, may be able to be executed in parallel during playback of the test script to test the AUT. The tests may be assigned to different testing devices of the same or different types. Parallel test execution permits AUT testing to occur more quickly and thus more efficiently. Testing efficiency is particularly beneficial during load testing of the AUT, to assess whether the AUT is likely to have satisfactory performance when a large number of end users are using the AUT at the same time.

However, dividing the test commands of a test script into tests that can be successfully performed in parallel is a difficult process. A tester may have to manually divide the test commands of a test script into tests in a seemingly arbitrary manner, and then attempt parallel execution of the tests. If a test cannot be successfully performed in parallel with another test, this means that its execution is conditioned on the prior execution of the latter test and has to be merged back together with the prior test. The tester may thus have to painstakingly perform multiple iterations of dividing test commands into tests and attempt their parallel execution to identify tests that can be successfully executed in parallel.

Techniques described herein ameliorate these and other difficulties. To preliminarily divide the test commands of a test script into tests, the test commands can first be sequentially executed. A parameter, such as a user interface parameter, can be monitored as the test commands are executed. The test commands can be preliminarily divided into tests in correspondence with changes in the parameter between consecutive test commands greater than a threshold. That is, the parameter changing by more than the threshold after execution of a test command signifies the start of a new test.

Once the test commands have been divided into tests, an analysis tree of the tests can be generated to identify the tests that can actually be successfully performed in parallel. The unique paths through the analysis tree correspond to all the different ways in which the tests can be grouped for parallel execution, with each unique path including a subset of the tests as in the test script. A maximally parallel subset of the unique paths that covers all the tests and that can be successfully executed is identified. That is, while the tests of a unique path are performed in sequential order, the maximally parallel subset's unique paths themselves are run in parallel. The tests of a unique path are thus in effect merged back together for execution.

Once the maximally parallel subset of the unique paths has been identified, each unique path of tests may be assigned to testing devices for subsequent execution. The testing devices may be of different types, and different tests may not be able to be executed on certain types of testing devices. Execution of the tests of each unique path is attempted on testing devices of each type. If any test of a unique path fails execution on testing devices of a given type, then the unique path is not subsequently assigned to such testing devices for execution.

The techniques described herein can therefore identify the most efficient manner in which the test commands of a test script can be grouped for parallel execution. The division of the test commands over tests provides a preliminary and thus best case of such parallel execution, if the identified tests can be successfully performed in parallel. However, generating an analysis tree of the tests and identifying the maximally parallel subset of unique paths through the tree that covers all the tests and that can be successfully executed, effectively merges the tests back together in correspondence with the largest number of groups of test commands that can be successfully run in parallel.

FIG. **1** shows an example test script **100**. The test script **100** may be for an AUT. The test script **100** includes sequentially ordered test commands **102**. The test commands **102** may each correspond to the selection or actuation of a user interface object of the AUT. The test script **100** may be manually recorded by a tester actuating the user interface objects of the AUT in a desired sequence, for instance. Subsequent playback of the test script **100** in an automated scaled-up manner on multiple testing devices, by the devices executing or running the test commands **102**, effectuates load testing in particular of the AUT.

In the example of FIG. **1**, the test commands **102** of the test script **100** have been preliminarily divided into tests **104**. The tests **104** are groups of the test commands **102**. The tests **104** are sequentially ordered within the test script **100** in correspondence with the test commands **102** that the tests **104** encompass. Each test **104** encompasses a different sequentially contiguous subset of the test commands **102**. Each test command **102** is encompassed by just one test **104**, such that the tests **104** do not overlap one another.

The tests **104** into which the test commands **102** have been organized can represent a preliminary grouping of the test commands **102** into a best case set of groups, or tests **104**, that can be executed in parallel. However, in actuality some of the tests **104** may not be able to be executed in parallel with the other tests **104**. Therefore, the tests **104** may in effect have to be selectively merged back together until they can be successfully performed in parallel.

FIG. **2** shows an example non-transitory computer-readable data storage medium **200**. The computer-readable data storage medium **200** stores program code **202** executable by a processor, such as that of a computing device like a desktop or laptop computer, a server, or another type of a computing device. The program code **202** is executable by the processor to perform processing for preliminarily dividing the test commands **102** of the test script **100** for an AUT into tests **104**.

The processing includes causing sequential execution of the test commands **102** of the test script **100** (**204**), as ordered in the test script **100**. The processing includes, as the test commands **102** are sequentially executed, monitoring a parameter (**206**). The parameter may be a user interface parameter or another parameter, which may change with the execution of each test command **102** of the test script **100**. Examples of such a user interface parameter in particular are described later in the detailed description.

The processing includes dividing the test commands **102** over tests **104** of the test script **100** (**208**), such as in

correspondence with changes in the parameter greater than a threshold. The changing of the parameter by more than the threshold at execution of a test command **102**, for instance, can signify a new test **104** beginning with the test command **102** in question. The division of the test commands **102** into tests **104** may be a preliminary such division, with the tests **104** in effect selectively merged back together depending on whether they can be successfully performed in parallel.

FIGS. **3**A and **3**B show an example as to how a change in a user interface parameter can signify the start of a new test **104**. FIGS. **3**A and **3**B specifically show a user interface **300** exposed by an AUT. The user interface **300** includes different selectable tabs **302**A, **302**B, **302**C, and **302**D, which are collectively referred to as the tabs **302**. The tabs **302** are examples of user interface objects of the AUT.

In FIG. **3**A, a first test command **102** is executed in the context of the tab **302**A. That is, the tab **302**A is the user interface object that is the subject of execution of this first test command **102**. By comparison, in FIG. **3**B, a consecutive, second test command **102** is executed in the context of the tab **302**B. That is, the tab **302**B is the user interface object that is the subject of execution of the second test command **102**. For instance, the second test command **102** may correspond to initial selection of the tab **302**B, in relation to which subsequent test commands **102** may be executed.

The user interface parameter in the example of FIGS. **3**A and **3**B is the user interface object that is the subject of execution of the test commands **102** of the test script **100**. The user interface parameter has changed from execution of the first test command **102** of FIG. **3**A to execution of the second test command **102** of FIG. **36**, because the test commands **102** pertain to different user interface objects: the tab **302**A in FIG. **3**A and the tab **3026** in FIG. **3**B. Insofar as the user interface object has changed, it is said that the user interface parameter has changed by more than the threshold, which is a qualitative as opposed to a quantitative threshold in this respect.

Therefore, the second test command **102** signifies the start of a new test **104**, beginning with the second test command **102**. The first test command **102** is the last test command **102** of the prior test **104**. The border between these two adjacent tests **104** thus corresponds to a change in a user interface parameter—a user interface object—from execution of the first test command **102** in FIG. **3**A to execution of the second test command **102** in FIG. **3**B. FIGS. **3**A and **38** therefore show how monitoring the user interface object that is the subject of test commands **102** can be used to divide the test commands **102** into tests **104** of the test script **100**.

FIG. **4** shows another example as to how a change in a user interface parameter can signify the start of a new test **104**. FIG. **4** shows a screenshot of a user interface **400** exposed by an AUT. Execution of a test command **102** has resulted in a changed portion **402** of the user interface **400** relative to the prior test command **102**, as well as an unchanged portion **402**. The changed portion **402** is more than a threshold percentage of the user interface **400** as a whole.

Therefore, the execution of the test command **102** that resulted in this change of the user interface **400** by more than the threshold percentage signifies the start of a new test **104**, beginning with the test command **102** in question. The user interface parameter in the example of FIG. **4** is the screenshot of the user interface **400**. FIG. **4** thus shows how monitoring the screenshot of the user interface **400** as to how much of the user interface **400** changes as a result of execution of test commands **102** can be used to divide the test commands **102** into tests **104** of the test script **100**.

FIGS. **5**A and **5**B show a third example as to how a change in a user interface parameter can signify the start of a new test **104**. FIGS. **5**A and **5**B show a user interface **500** exposed by an AUT. In FIG. **5**A, execution of a first test command **102** results in a change in the user interface **500** within a portion **502**. In FIG. **5**B, execution of a consecutive, second test command **102** results in a change in the user interface **500** within a different portion **504**. The execution of the second test command **102** that resulted in a change in the user interface **500** within the different portion **504** as compared to execution of the immediately prior first test command **102** signifies the start of a new test **104**, beginning with the second test command **104**.

The user interface parameter in the example of FIGS. **5**A and **5**B is the portion within the screenshot, such as of the user interface **500**, which changed during test command execution. Insofar as the portion **504** within the screenshot that changed in FIG. **5**B is different than the portion **502** in FIG. **5**A, it is said that the user interface parameter has changed by more than the threshold. FIGS. **5**A and **5**B thus show how monitoring which portion of the screenshot of the user interface **500** changes as a result of execution of test commands **102** can be used to divide the test commands **102** into tests **104** of the test script **100**.

FIG. **6** shows an example method **600** for dividing the test commands **102** of the test script **100** over tests **104**. The method **600** can be performed to implement part **208** of FIG. **2**, after monitoring of a parameter as the test commands **102** have been sequentially performed. The method **600** can be implemented as program code stored on a non-transitory computer-readable data storage medium and executable by a processor of a computing device.

The method **600** defines a first test **104** as starting with the first test command **102** of the test script **100** (**602**). A current test **104** is set to the first test **104** (**604**), and a current test command **102** is set to the second test command **102** (**606**). If the change in the parameter from the prior test command **102** to the current test command **102** is not greater than a threshold (**608**), and if the current test command **102** is not the last test command **102** of the test script **100** (**610**), the method **600** advances the current test command **102** to the next test command **102** within the test script **100** (**612**). The method **600** is then repeated at part **608**.

However, if the change in the parameter from the prior test command **102** to the current test command **102** is greater than the threshold (**608**), then the definition of the current test **104** is completed as ending with the current test command **102** (**614**). If the current test command **102** is not the last test command **102** of the test script **100** (**616**), the current test command **102** is advanced to the next test command **102** within the test script **100** (**618**), and a new current test **104** is defined as starting with the current test command **102** (**620**). The method **600** is then repeated at part **608**.

If the change in the parameter from the prior test command **102** to the current test command **102** is not greater than the threshold (**608**), and the current test command **102** is the last test command **102** of the test script **100** (**610**), the definition of the current test **104** is completed as ending with the current test command **102** (**622**). The method **600** is then finished (**624**). Similarly, if the change in the parameter from the prior test command **102** to the current test command **102** is greater than the threshold (**608**), resulting in completion of the definition of the current test **104** with the current test command (**614**), and the current test command **102** is the last test command **102** (**616**), the method **600** is finished (**624**).

The method **600** thus defines the first test **104** of the test script **100** starting with the first test command **102** of the script **100**, and ends the first test **104** at the test command **102** prior to the test command **102** at which the parameter changes by more than the threshold, or at the last test command **102**. If there are more test commands **102** when the first test **104** has its definition completed, then the method **600** starts a new test **104** with the test command **102** at which the parameter changes by more than the threshold. This process is repeated until the method **600** reaches the last test command **102** of the test script **100**. The current test command **102** being the last test command **102** of the script **100** can thus be considered the exit condition that is set or satisfied to exit this repeating process.

Each test **104** of the test script **100** spans a contiguous subset of the test commands **102** within the test script **100**, with adjacent tests **104** separated at borders between adjacent test commands **102** between which the parameter changes by more than the threshold. The tests **104** are sequentially ordered over the test commands **102** of the test script **100**. The first test **104** starts at the first test command **102** of the test script **100**, and every other test **104** starts at a test command **102** of the test script **100** at which the change in the parameter from the prior test command **102** is greater than the threshold.

FIGS. 7A, 7B, and 7C show examples of how three tests **702**A, **702**B, and **702**C over which the test commands of a test script may have been preliminarily divided can be executed in different parallel and serial combinations. The tests **702**A, **702**B, and **702**C are collectively referred to as the tests **702**. In FIG. 7A, there is one unique path made up of tests **702**A, **702**B, and **702**C ordered in the sequence in which their test commands are executed within the test script. The unique path of FIG. 7A is the absolute minimally parallel unique path (i.e., the absolute maximally serial unique path) that encompasses all tests **702**, because none of the tests **702** are executed in parallel. In FIG. **7**A, the tests **702** can be considered to have in effect been merged back together, since all are performed in sequence within one unique path and none are performed in parallel.

In FIG. **76**, there are two unique paths: a unique path encompassing tests **702**A and **702**B, in which the test **702**A is executed before the test **7028**, and a unique path encompassing just test **702**C. The two unique paths are executed in parallel to one another, and together encompass all tests **702**. In FIG. 7B, the tests **702**A and **702**B can be considered to have in effect been merged back together, since the test **702**B is performed in sequence after the test **702**A in the same chain, and the chain of tests **702**A and **702**B is performed in parallel with the test **702**C.

Similarly, in FIG. 7C, there are two unique paths: a unique path encompassing just test **702**A, and a unique path encompassing tests **702**B and **702**C, in which the test **702**B is executed before the test **702**C. The two unique paths are executed in parallel to one another, and together encompass all tests **702**. In FIG. 7C, the tests **702**B and **702**C can be considered to have in effect been merged back together, since the test **702**C is performed in sequence after the test **702**B in the same chain, and the chain of tests **702**B and **702**C is performed in parallel with the test **702**A.

In FIG. 7D, there are three unique paths respectively encompassing the tests **702**A, **702**B, and **702**C, and this set of unique paths encompasses all tests **702**. The set of unique paths of FIG. 7D is the absolute maximally parallel set of unique paths that encompasses all tests **702**, because all tests

702 are executed in parallel. This set can also be referred to as the absolute minimally serial set of unique paths.

FIGS. **7**A, **7**B, **7**C, and **7**D thus show various ways in which the tests **702** can be organized over unique paths that are executed in parallel with one another, where the tests of any given path are sequentially executed as per their order within the test script, in the case in which the test script has been preliminarily divided over three tests **702**. However, the tests **702** may not be successfully executable pursuant to every figure. For example, of the tests **702**B and **702**C that have been preliminarily identified, performing the test **702**C in parallel with the test **702**B may not be successful. Rather, the test **702**C may have to have its execution conditioned on the prior execution of the test **702**B.

In this example, this means that the unique paths into which the tests **702** have been organized in FIGS. **76** and **7**D cannot be successfully executed, because the test **702**C is executed in parallel with the test **702**B in these figures. That is, the tests **702**B and **702**C belong to different unique paths in FIGS. **78** and **7**D. The tests **702**B and **702**C have to in effect be merged back together after having been preliminarily identified, as is the case in FIGS. **7**A and **7**C.

Continuing with this example, if the test **702**B also has its execution conditioned on the prior execution of the test **702**A, then the most efficient way to execute the tests **702** is in accordance with FIG. **7**A. This is because the tests **702**A and **702**B have to be executed as part of the same unique path and thus effectively merged back together, and they are not in FIG. **7**C. However, if the test **702**B can be successfully executed in parallel with the test **702**A, then the most efficient way to execute the tests **702** is in accordance with FIG. **7**C, because FIG. **7**C has more unique paths than FIG. **7**A, and the paths of FIG. **7**C are each shorter in length than the path of FIG. **7**A.

The chains of FIGS. **7**A, **7**B, **7**C, and **7**D in which the tests **702** can be executed in various parallel and serial combinations constitute a set of unique chains. Each of FIGS. **7**A, **7**B, **7**C, and **7**D specifies a subset of these unique chains that covers all the tests **702**, and in which each test **702** appears just once. In the described example, in which the test **702**C cannot be successfully executed in parallel with the test **702**B but the test **702**A can be executed in parallel with both tests **702**B and **702**C, the subset of unique chains of FIG. **7**C is the maximally parallel subset of the unique chains in which the tests **702** can be successfully executed.

FIG. **8** shows an example method **800** for identifying the maximally parallel subset of unique paths of tests into which a test script has been preliminarily divided and that can be successfully executed in parallel. The method **800** can be performed by a processor of a computing device. The method **800** includes (preliminarily) dividing the test script into tests (**802**), such as has been described in relation to FIG. **2**.

The method **800** includes generating an analysis tree of the tests having unique paths through the tree and that each include a subset of the tests as sequentially ordered within the test script (**804**). An example of such an analysis tree and how the analysis tree can be generated are described later in the detailed description. In the case of a test script that has been divided into three tests, the set of unique paths through the analysis tree corresponds to the set of unique paths that have been described in relation to FIGS. **7**A, **7**B, **7**C, and **7**D.

The method **800** includes then identifying the maximally parallel subset of unique paths through the analysis tree that covers all tests and that according to which the tests are successfully executable (**806**). An example as to how the

maximally parallel subset can be identified is described later in the detailed description. As noted above, the absolute maximally parallel subset of the unique paths is that in which each unique path includes just one test, such that all the tests are executed in parallel (since all the paths are executed in parallel). However, the absolute maximally parallel subset is not the maximally parallel subset that can be successfully executed if the execution of any test is conditioned on the execution of another test. Further, each test appears in only one unique path of the identified maximally parallel subset.

FIG. **9** shows an example analysis tree **900** for a test script that has been preliminarily divided over four tests **904**A, **904**B, **904**C, and **904**D, which are collectively referred to as the tests **904**. In the example of FIG. **9**, the first test **904**A appears once in the analysis tree **900**; the second test **904**B appears twice; the third test **904**C appears four times; and the fourth test **904**D appears eight times. In general, the n-th test **904** appears 2^(n−1) times in the analysis tree **900** in the example of FIG. **9**.

There is an edge from a root node **902** to each test **904** of the test script in a first level of the analysis tree **900**. From each test **904** in the first level, there is an edge to every test **904** in a second level of the analysis tree **900** that appears after the test **904** within the test script. For example, from the test **904**A in the first level there are edges to tests **904**B, **904**C, and **904**D in the second level, since the tests **904**B, **904**C, and **904**D are sequentially ordered after the test **904**A within the test script.

Similarly, from the test **904**B in the first level of the analysis tree **900** there are edges to tests **904**C and **904**D in the second level, since the tests **904**D and **904**D are sequentially ordered after the test **904**B within the test script. There is no edge from the test **904**B in the first level to the test **904**A in the second level. This is because the test **904**A is sequentially ordered before the test **904**B within the test script.

From the test **904**C in the first level there is an edge to the test **904**D in the second level, since the test **904**D is sequentially ordered after the test **904**C within the test script. There are no edges from the **904**C in the first level to the tests **904**A and **904**B in the second level, because the tests **904**A and **904**B are sequentially ordered before the test **904**C within the test script. Similarly, there are no edges from the test **904**D in the first level to any test **904** in the second level, because no test **904** is sequentially ordered after the test **904**D within the test script (i.e., the test **904**D is the last test **904** in the test script).

From the test **904**B in the second level there are edges to just the tests **904**C and **904**D in the third level, since just the tests **904**C and **904**D are sequentially ordered after the test **904**B within the test script. From the test **904**C in the second level there is an edge to just the test **904**D in the third level, since just the test **904**D is sequentially ordered after the test **904**C within the test script. There are no edges from the test **904**D in the second level to any test **904** in the third level, because no test **904** is sequentially ordered after the test **904**D within the test script.

From the test **904**C in the third level there is an edge to just the test **904**D in the fourth level, since just the test **904**D is sequentially ordered after the test **904**C within the test script. There are no edges from the test **904**D in the third level to any test **904** in the fourth level, because no test **904** is sequentially ordered after the test **904**D within the test script. There is no fifth level within the analysis tree **900**, because the sole test **904**D in the fourth level is the last test **904** within the test script.

Each chain of one or more edges traversing one or more tests **904** is a unique path within the analysis tree **900**. For example, there is a unique path between the root node **902** and each test **904** in the first level; between each test **904** in the first level and every test **904** in the second level to which the test **904** is connected via an edge; and so on. These unique paths each include one edge and traverse one or two tests **904**.

Other unique paths can include more than one edge and traverse more than two tests **904**. For example, there is a unique path from the root node **902** to the test **904**A in the first level, to the test **904**B in the second level, to the test **904**C in the third level, and to the test **904**D in the fourth level. As another example, there is a unique path from the root node **902** to the test **904**B in the second level to the test **904**D in the third level. In general, a unique path starts at the root node **902** or at any test **904** within any level other than the last level of the analysis tree **900**, and continues along one or more edges before ending at any other test **904** within a lower level of the tree **900**.

FIG. **10** shows an example method **1000** for generating an analysis tree of the tests into which a test script has been preliminarily divided. The method **1000** can be performed to realize part **804** of the method **800** of FIG. **8**. The method **1000** can be performed by a processor of a computing device. The method **1000** can be implemented as a non-transitory computer-readable data storage medium storing program code executable by this processor. The method **1000** begins by adding a root node at the top of the analysis tree (**1002**), and adding a child node for each test of the test script in a first level of the tree, with a connecting edge between the root node and each such child node (**1004**).

The method **1000** includes setting a current level of the analysis tree to the first level of the tree (**1006**). The method **1000** includes setting a current node to the first node of the current level of the analysis tree (**1008**). If the test of the current node (i.e., the test to which the current node corresponds) is not the last test of the test script (**1010**), then the method **1000** includes adding, in the next level of the analysis tree, a child node for each test that is ordered after the test of the current node within the test script, along with a connecting edge from the current node (**1012**). The method **1000** includes then advancing the current node to the next node in the current level of the analysis tree (**1014**), before proceeding back to part **1010**.

Once the test of the current node is the last test of the test script (**1010**), if the current level is not the last level of the analysis tree (**1016**), the method **1000** includes advancing the current level to the next level of the analysis tree (**1018**). The method **1000** then proceeds back to part **1008**. Once the test of the current node is the last test of the test script (**1010**), and the current level is the last level of the analysis tree (**1016**), the method **1000** is finished (**1020**).

FIG. **11** shows an example method **1100** for identifying a maximally parallel subset of unique paths through an analysis tree that cover all tests of a test script and according to which the tests can be successfully executed. The method **1100** can be performed to realize part **806** of the method **800** of FIG. **8**. The method **1100** can be performed by a processor of a computing device. The method **1100** can be implemented as a non-transitory computer-readable data storage medium storing program code executable by this processor.

A subset of unique paths through an analysis tree covers all the tests of a test script if every test of the test script is traversed within the subset. The tests are executable according to a subset of unique paths in that each unique path is executed in parallel. That is, the tests of one unique path are

executed in parallel with the tests of another unique path, and so on. The tests of a given unique path are executed sequentially, in their order within the test script.

The tests are successfully executable according to a subset of unique paths if the unique paths can be executed in parallel without any test of any path failing. If two tests are assigned to different unique paths and thus executed in parallel, but the execution of the first test is conditioned on the execution of the second test, then execution of the first test will fail. A subset of unique paths according to which the tests are successfully executable is the maximally parallel such subset if it includes the maximum number of unique paths of any such successfully executable subset.

The method **1100** includes initially marking each edge of the analysis tree as permissible (**1102**). That an edge is permissible means that the edge can be included when identifying a maximally parallel subset of unique paths. The method **1100** thus identifies the maximally subset of unique paths through the analysis tree that covers all the tests and that traverses only permissible edges of the tree (**1104**). Because all the edges are permissible the first time part **1104** is performed, such initial performance of part **1104** results in each test having its own unique path (viz., each unique path includes just one test) in the identified maximally parallel subset.

The method **1100** includes then attempting to execute the tests according to the identified maximally parallel subset of unique paths (**1106**). The unique paths of tests are executed in parallel, with tests belonging to the same unique path being executed sequentially according to their order within the test script. Execution of any given test may succeed or fail. Execution of a first test will fail if it is executed in parallel with a second test, but the first test's execution is conditioned on the execution of the second test (i.e., the first test is part of a different unique path than the second test).

The method **1100** includes marking the edge leading to any test that was not successfully executed as impermissible (**1108**). If any edges were marked as impermissible in the most recently identified maximally parallel subset of unique paths (**1110**), then the method **1100** is repeated at part **1104**. In other words, if any edges were marked as impermissible, the tests cannot be successfully executed according the identified maximally parallel subset of unique paths. Therefore, the maximally parallel subset of unique paths has to again be identified so as not to traverse the impermissible edges.

In one implementation, the tests are attempted to be executed in part **1106** according to the identified maximally parallel subset of unique paths a number of times (i.e., a number of execution attempts). In this implementation, an edge leading to a test is marked as impermissible if it was not successfully executed more than a threshold number of these times or execution attempts. Such an implementation can ensure that outlier failed executions of any given test are not considered in marking its leading edge as impermissible.

Each time the maximally parallel subset of unique paths is identified at part **1104**, the subset will likely be less parallel (and will be no more parallel) than before. This is because part **1104** is repeated when edges included in the identified maximally parallel subset have been marked as impermissible, such that these edges cannot be included when the maximally parallel subset of unique paths is identified again. Once no edges traversed by the most recently identified maximally parallel subset of unique paths have been marked as impermissible (**1110**), the method **1100** is finished. The most recently identified maximally parallel subset of unique paths is the maximally parallel such subset according to which the tests of the test script can be successfully executed.

FIGS. **12**A, **12**B, and **12**C depict example performance of the method **1100** with respect to the analysis tree of FIG. **9**. In FIG. **12**A, all the edges of the analysis tree have been initially marked as permissible, as indicated by checkmarks, per part **1102** of the method **1100**. The maximally parallel subset of unique paths that covers all the tests is thus determined in initial performance of part **1104** as the subset of the four paths respectively leading to the nodes for the tests **904** from the root node **902**, including the edges leading to these nodes from the root node **902**.

Specifically, the first path of the initially identified maximally parallel subset of unique paths includes the node for the test **904**A and the edge leading to this node from the root node **902**. The second path of this subset includes the node for the test **904**B and the edge leading to this node from the root node **902**. The third path includes the node for the test **904**C and the edge leading to this node from the root node **902**, and the fourth path includes the node for the test **904**D and the edge leading to this node from the root node **902**.

Attempted execution of the tests **904** according to this identified maximally parallel subset of unique paths per part **1106** of the method **1100** may, for example purposes, result in successful execution of the tests **904**A, **904**B, and **904**D, but unsuccessful execution of the test **904**C. Therefore, in FIG. **12**B, the edge leading to the test **904**C from the root node **902**, which is encompassed by the identified maximally parallel subset of unique paths, is marked as impermissible, as indicated by an X, per part **1008**. The maximally parallel subset of unique paths is thus identified again, again per part **1104**.

The newly identified maximally parallel subset of unique paths again includes paths that respectively lead to the nodes for the tests **904**A, **904**B, and **904**C from the root node **902**, including the edges leading to these nodes from the root node **902**. This maximally parallel subset, though, does not include a path leading to the node for the test **904**C from the root node **902**, nor the edge leading to this node from the root node **902**, because the edge is now impermissible. The node for the test **904**C still has to be covered by the maximally parallel subset of unique paths, however.

In one alternative, the node for the test **904**C may be covered by the unique path that also covers the node for the test **904**A. In this case, the unique path in question includes the edge from the root node **902** to the node for the test **904**A, and the edge from this latter node to the node for the test **904**C. In another alternative, the node for the test **904**C may instead be covered by the unique path that also covers the node for the test **904**B. In this case, the unique path in question includes the edge from the root node **902** to the node for the test **904**B, and the edge from this latter node to the node for the test **904**C.

The two alternatives have the same degree of parallelism, and therefore either can be selected as part of the maximally parallel subset of unique paths that covers all the tests **904** and that traverses only permissible (and not impermissible) edges. For example purposes, it is assumed that the first alternative is chosen. Attempted execution of the tests **904** according to this identified maximally parallel subset of unique paths, per part **1106** of the method **1100**, may result in successful execution of all the tests **904**. Therefore, this identified maximally parallel subset of unique paths is deemed the maximally parallel such subset that covers all the tests **904** and according to which the tests **904** can be successfully executed.

FIG. **12**C shows this maximally parallel subset of unique paths. The first unique path includes the tests **904**A and **904**C. The test **904**C is executed after the test **904**A, because the test **904**C is ordered after the test **904**A within the test script. The second unique path includes the test **904**B, and the third unique path includes the test **904**C. The three unique paths are executed in parallel. Therefore, the sequential execution of the tests **904**A and **904**C occurs in parallel with the execution of the test **904**B, and in parallel with the execution of the test **904**D.

Once the maximally parallel subset of unique paths covering all the tests and according to which the tests can be successfully executed has been identified, the unique paths of tests can be concurrently executed on testing devices. However, testing devices may be of different types. Although the tests are successfully executable according to maximally parallel subset of unique paths, different tests may not in actuality be able to be successfully executed on certain types of testing devices. Therefore, for concurrent execution of the unique paths of tests, the tests can be assigned just to testing devices of types on which they can be successfully executed.

FIG. **13** shows an example system **1300** in this respect. The system **1300** includes testing devices **1302** of different testing device types **1304**, as well as a testing manager device **1306**. The testing devices **1302** and the testing manager device **1306** may be computing devices like desktop or laptop computers, servers, or other computing devices. The testing devices **1302** may differ in their types **1304** by constituent hardware components, such as processor type and operating frequency; memory type, amount, and operating frequency; storage device type and capacity; and so on. The testing devices **1302** may additionally or alternatively differ in their types **1304** as to the software they run, such as operating system type and version.

The testing manager device **1306** can perform the methods that have been described and can execute the program code that has been described. The testing manager device **1306** stores a test script **1308** of tests **1310**, as well as a maximally parallel subset of unique paths **1312** that covers all the tests **1310** and according to which the tests **1310** can be successfully executed. For each unique path of tests **1310**, the testing manager device **1306** assigns the tests **1310** covered by the unique path to the testing devices **1302** of testing device types **1304** on which every test **1310** of the unique path can be successfully executed.

For example, a unique path of tests **1310** may include a first test **1310** and a second test **1310**. The testing devices **1302** may include testing devices **1302** of a first type **1304** and testing devices **1302** of a second type **1304**. The first test **1310** may be able to be executed successfully on testing devices **1302** of both the first and second types **1304**, whereas the second test **1310** may be able to be executed successfully on testing devices **1302** of just the second type **1304**. Therefore, both the first and second tests **1310** are assigned to testing devices **1302** of just the second type **1304**.

The first test **1310** also has to be assigned to testing devices **1302** of just the second type **1304**, even though it can be successfully executed on testing devices **1302** of the first type **1304**, because execution of the second test **1310** is conditioned on execution of the first test **1310** (since the two tests **1310** are in the same unique path). The assigned testing device **1302** first performs the first test **1310**, and then performs the second test **1310**. Execution of the second test **1310** on a different testing device **1302** than the testing device **1302** on which the first test **1310** may not be successful, in other words, such that both tests **1310** have to be executed (and thus assigned for execution) on the same testing device **1302** of the second type **1304**.

FIG. **14** shows an example method **1400** for assigning the tests **1310** of the test script **1308** covered by a maximally parallel subset of unique paths **1312** to testing devices **1302** of different types **1304** for concurrent execution of the unique paths of tests **1310**. The testing manager device **1306** can perform the method **1400**. The method **1400** may be implemented as program code stored on a non-transitory computer-readable data storage medium, and executable by a processor of the testing manager device **1306**.

The method **1400** includes, for each unique path of tests **1310**, attempting execution of the tests **1310** covered by the path on testing devices **1302** of each type **1304** (**1402**). For each type **1304** of the testing devices **1302**, execution of each test **1310** may be successful or unsuccessful. Therefore, for each unique path, the method **1400** marks as permissible each type **1304** of the testing devices **1302** on which any test **1310** covered by the path failed (**1404**).

The method **1400** includes, for each unique path of tests **1310**, then assigning the tests **1310** covered by the path to testing devices **1302** of types **1304** that have not been marked as impermissible for that path (**1406**). That is, the tests **1310** covered by a unique path are assigned to testing devices **1302** other than those of any impermissible testing device type **1304** for the path. The method **1400** can include subsequently causing concurrent execution of the unique paths of the tests **1310** on their assigned testing devices (**1408**).

Techniques have been described for identifying the most efficient manner in which the test commands of a test script for an AUT can be grouped for parallel execution, to improve load testing performance of the AUT. The test commands can be preliminarily divided over tests. A maximally parallel subset of unique paths of the tests can then be identified to effectively merge tests back together as necessary. The unique paths of tests of the resultantly identified maximally parallel subset can thus be concurrently executed (viz., in parallel) to efficiently load test the AUT.

We claim:

1. A method comprising:
- dividing, by a processor, a test script into a plurality of tests, the tests having a sequential order within the test script;
- generating, by the processor, an analysis tree of the tests, each of a plurality of unique paths through the analysis tree including a subset of the tests as sequentially ordered within the test script;
- identifying, by the processor, a maximally parallel subset of the unique paths that covers all the tests and according to which the tests are successfully executable, each test appearing in only one unique path of the maximally parallel subset; and
- causing, by the processor, execution of the tests of the test scripts on a plurality of testing devices according to the maximally parallel subset of the unique paths.

2. The method of claim **1**, wherein identifying the maximally parallel subset of the unique paths comprises:
- initially marking each of a plurality of edges of the analysis tree as permissible, each edge connecting a pair of the tests according to the sequential order; and
- repeatedly:
  - identifying the maximally parallel subset of the unique paths that covers all the tests, the edges covered by the maximally parallel set all being permissible;
  - attempting to execute the tests according to the maximally parallel subset of the unique paths; and
  - marking the edge leading to any test that was not successfully executed as impermissible,
- until no edge within the maximally parallel subset of the unique paths that covers all the tests has been marked as impermissible.

3. The method of claim **2**, wherein attempting to execute the tests according to the maximally parallel subset of the unique paths comprises:
- performing a plurality of execution attempts according to the maximally parallel subset of the unique paths,
- and wherein marking the edge leading to any test that was not successfully executed as impermissible comprises:
- marking the edge leading to any test that was not successfully executed in more than a threshold number of the execution attempts as impermissible.

4. The method of claim **1**, wherein causing the execution of the tests of the test scripts according to the maximally parallel subset of the unique paths comprises, for each unique path of the maximally parallel subset of the unique paths:
- attempting the execution of the tests covered by the unique path on the testing devices of each of a plurality of testing device types; and
- marking, as an impermissible testing device type for the unique path, each testing device type of the testing devices on which the execution of any test covered by the unique path failed.

5. The method of claim **4**, wherein causing the execution of the tests of the test scripts according to the maximally parallel subset of the unique paths further comprises:
- for each unique path of the maximally parallel subset of the unique paths, assigning the tests covered by the unique path to the testing devices other than the testing devices marked as the impermissible testing device type for the unique path; and
- concurrently causing the execution of the tests covered by each unique path of the maximally parallel subset of the unique paths on the testing devices to which the tests have been assigned.

6. The method of claim **1**, wherein dividing the test script into the tests comprises:
- causing sequential execution of a plurality of ordered test commands of the test script;
- as each ordered test command is sequentially executed, monitoring a parameter; and
- dividing the ordered test commands over the tests in correspondence with changes in the parameter greater than a threshold.

7. The method of claim **6**, wherein the parameter comprises a user interface parameter.

8. A non-transitory computer-readable data storage medium storing program code executable by a processor to perform processing comprising:
- causing sequential execution of a plurality of test commands of a test script, the test commands sequentially ordered within the test script;
- monitoring a parameter as the test commands are sequentially executed;
- dividing the test commands over a plurality of tests of the test script in correspondence with changes in the parameter greater than a threshold;
- generating an analysis tree of the tests, each of a plurality of unique paths through the analysis tree including a subset of the tests as sequentially ordered within the test script; and

identifying a maximally parallel subset of the unique paths that covers all the tests and according to which the tests are successfully executable, each test appearing in only one unique path of the maximally parallel subset; and

causing execution of the tests of the test scripts on testing devices according to the maximally parallel subset of the unique paths.

9. The non-transitory computer-readable data storage medium of claim **8**, wherein dividing the ordered test commands over the tests in correspondence with the changes in the parameter greater than the threshold comprises:

defining a current test starting with a first test command of the test script;

setting a current test command to a second test command of the test script;

repeatingly:

in response to a change in the parameter from a prior test command to the current test command being greater than the threshold, completing definition of the current test as ending with the prior test command and, in response to the current test command not being a last test command of the test script, defining a new current test starting with the current test command;

in response to the current test command being the last test command of the test script, setting an exit condition; and

in response to the current test command not being the last test command of the test script, advancing the current test command to a next test command of the test script,

until the exit condition has been set.

10. The non-transitory computer-readable data storage medium of claim **8**, wherein the tests are sequentially ordered over the test commands of the test script, a first test starts at a first test command of the test script, and every other test starts at a test command of the test script at which a change in the parameter from a prior test command of the test script is greater than the threshold.

11. The non-transitory computer-readable data storage medium of claim **8**, wherein the tests do not overlap one another in encompassing the test commands, each test encompasses a different sequentially contiguous subset of the test commands, and each test command is encompassed by just one of the tests.

12. The non-transitory computer-readable data storage medium of claim **11**, wherein a border between each pair of a plurality of pairs of adjacent tests corresponds to a change in the parameter from a last test command encompassed by a first test of the pair to a first test command encompassed by a second test of the pair being greater than the threshold.

13. The non-transitory computer-readable data storage medium of claim **8**, wherein the parameter comprises a user interface parameter.

14. The non-transitory computer-readable data storage medium of claim **13**, wherein the user interface parameter comprises one or more of:

a user interface object that is a subject of execution of a test command of the test script;

a screenshot after the execution of the test command; and

a portion within the screenshot that changed during the execution of the test command.

15. The non-transitory computer-readable data storage medium of claim **8**, wherein causing the execution of the tests of the test scripts according to the maximally parallel subset of the unique paths comprises:

for each unique path of the maximally parallel subset of the unique paths:

attempting execution of the tests covered by the unique path on the testing devices of each of a plurality of testing device types; and

marking, as an impermissible testing device type for the unique path, each testing device type of the testing devices on which the execution of any test covered by the unique path failed;

assigning the tests covered by the unique path to the testing devices other than the testing devices of any impermissible testing device type for the unique path; and

concurrently causing the execution of the tests covered by each unique path of the maximally parallel subset of the unique paths on the testing devices to which the tests have been assigned.

16. The non-transitory computer-readable data storage medium of claim **8**, wherein identifying the maximally parallel subset of the unique paths comprises:

initially marking each of a plurality of edges of the analysis tree as permissible, each edge connecting a pair of the tests according to the sequential order; and

repeatedly:

identifying the maximally parallel subset of the unique paths that covers all the tests, the edges covered by the maximally parallel set all being permissible;

attempting to execute the tests according to the maximally parallel subset of the unique paths; and

marking the edge leading to any test that was not successfully executed as impermissible,

until no edge within the maximally parallel subset of the unique paths that covers all the tests has been marked as impermissible.

17. A system comprising:

a plurality of testing devices of different testing device types;

a testing manager device to, for each unique path of a maximally parallel subset of unique paths that cover all tests into which a test script has been divided:

attempt execution of the tests covered by the unique path on the testing devices of the different testing device types;

mark, as an impermissible testing device type for the unique path, each testing device type of the testing devices on which the execution of any test covered by the unique path failed; and

assign the tests covered by the unique path to the testing devices other than the testing devices of any impermissible testing device type for the unique path,

wherein the testing manager device is further to concurrently cause the execution of the tests covered by each unique path of the maximally parallel subset of the unique paths on the testing devices to which the tests have been assigned.

18. The system of claim **17**, wherein the testing manager device is further to:

cause sequential execution of a plurality of test commands of the test script, the test commands sequentially ordered within the test script;

monitor a parameter as the test commands are sequentially executed in order;

divide the test commands over the tests of the test script in correspondence with changes in the parameter greater than a threshold;

generate an analysis tree of the tests, each unique path being through the analysis tree and including a subset of the tests as sequentially ordered within the test script; and

identify the maximally parallel subset of the unique paths as that which covers all the tests and according to which the tests are successfully executable, each test appearing in only one unique path of the maximally parallel subset.

19. The system of claim **18**, wherein the testing manager device is further to identify the maximally parallel subset of the unique paths by:

initially marking each of a plurality of edges of the analysis tree as permissible, each edge connecting a pair of the tests according to the sequential order; and

repeatedly:

identifying the maximally parallel subset of the unique paths that covers all the tests, the edges covered by the maximally parallel set all being permissible;

attempting to execute the tests according to the maximally parallel subset of the unique paths; and

marking the edge leading to any test that was not successfully executed as impermissible,

until no edge within the maximally parallel subset of the unique paths that covers all the tests has been marked as impermissible.

20. The system of claim **17**, wherein the testing manager device is further to:

divide the test script into the tests, the tests having a sequential order within the test script; and

generate an analysis tree of the tests, each of the unique paths being through the analysis tree and including a subset of the tests as sequentially ordered within the test script.

* * * * *